A COMPUTER SOLUTION FOR MULTIPLE SATELLITE-SATELLITE AND SATELLITE-GROUND STATION VISIBILITY DETERMINATION

prepared by:

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UTSI
31 July 1991

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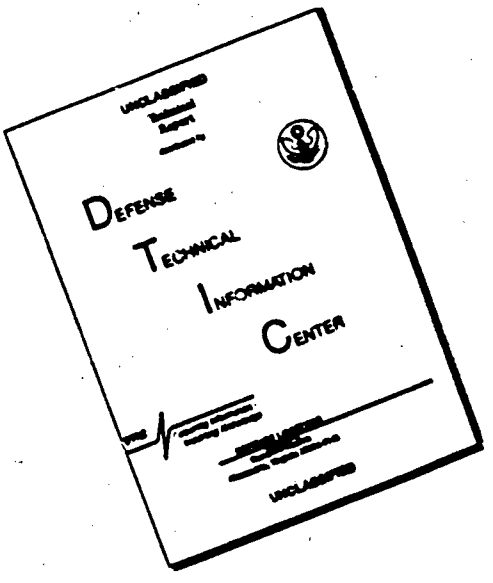

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ABSTRACT

The purpose of this study is to examine the problem of determining rise and set times for visibility periods of multiple satellite-satellite and satellite-ground station communications. Additionally, the ability to maintain constant communication links is explored.

This research examines three means to solve the problem: basic iteration, the Lawton Method, and an improved method involving parabolic blending and a closed form root solving technique. The greatest concentration is placed on the final solution and its application.

The result of this investigation is a computer program capable of determining rise and set times for as many as four satellites and four ground stations. In addition, the program performs a check for continuous communications between the indicated satellites and earth based resources.

ACKNOWLEDGEMENTS

This study represents the continued efforts of a project I began in a senior research study at the United States Air Force Academy. My task there was to research a computer method for rise/set determination between only two satellites using parabolic blending. My involvement with the project ended with the research, development, and early data collection. Two officers from the Academy, Lt Colonel Salvator Alfano and Captain Dave Negron continued their own research into this topic after my graduation and have since submitted the results of our total effort for publication (See reference 1).

For this project, I resumed my work where my own research had ended a year before. The data published from Lt Colonel Alfano and Captain Negron's continued efforts was very helpful in verifying the results of my own computer program. I am pleased to be able to bring to this project the added dimension of multiple satellite and ground station handling and continuous communications determination. I hope this paper provides insight into my own understanding of the problem and the course of my research as a whole. I am grateful to Lt Colonel Alfano and Captain Negron for their continued support and encouragement in this endeavor.

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LIST OF SYMBOLS AND ABBREVIATIONS

a	Semi-major axis
a_e	Radius of the earth
C_{max}	Greatest modulus of the FFT
e	Eccentricity
e_e	Eccentricity of the earth
E	Eccentric anomaly
FFT	Fast Fourier Transform
i	Inclination
H	Altitude above mean sea level
J_2	Second harmonic of the earth's gravitational potential
JD	Julian Date
L	Geodetic Latitude
M	Mean anomaly
n	Mean motion
n_o	Mean motion at epoch
n	Anomalistic mean motion
p	Semi-latus rectum
P	Period of the visibility waveform
R_E	Radius of the earth
r_1	Position vector of satellite =1
r_2	Position vector of satellite =2
T_u	Centuries until 1 January 2000
UT	Universal Time
α_1	Angle between earth's radius (perpendicular to tangent plane) and position vector =1, r_1

α_2	Angle between earth's radius (perpendicular to tangent plane) and position vector #2, r_2
$a_0,\ldots,a_3$	Coefficients of the cubic equation defined by parabolic blending
Γ	Visibility function
δ	East Longitude of the site
θ	Local Sidereal Time
θ_g	Greenwich Sidereal Time
θ_{go}	Greenwich Sidereal Time at 0 hours UT
Φ	Angle between r_1 and r_2
ν	True anomaly
Ω	Longitude of the ascending node
w	Argument of periapsis
$\nu_{j_{max}}$	Frequency of the largest modulus $C_{j_{max}}$

CHAPTER 1

INTRODUCTION

In space mission architecture, much rests on a satellite's ability to communicate with either an earth based tracking station or another satellite. Data relays as well as tracking, telemetry, and command directions depend on line of sight opportunities. Additionally, availability of communications determine satellite data rate requirements, data storage capabilities, and on orbit processing. All these factors affect satellite complexity, orbit selection and satellite constellation size. For these reasons, it is important to possess the ability to rapidly determine visibility rise and set times.

Three methods of determining the desired rise and set times are of interest to this study. The first propagates a basic visibility function then requires linear interpolation to find rise/set times. The second takes advantage of the fast Fourier transform to define characteristics of the visibility curve. This method makes use of the Regula Falsi iterative technique to determine rise/set times. The final method reconstructs the visibility curve using parabolic blending, then determines rise/set times using a closed form root solver. The process for determining visibility periods by this third method is detailed. The final result is a computer program capable of handling multiple satellites and ground stations, determining whether or not continuous

communications among the satellites and with the ground is possible, and completing the task in a timely manner.

CHAPTER 2

VISIBILITY FUNCTION

2.1 General Discussion

The concept of the visibility function is central to any method of determining rise/set times for satellite-satellite or satellite-ground station in-view periods. The visibility function involves a line of sight calculation between the two objects of interest. The value of the function varies with time in accordance to the changing positions of the two objects.

For two satellites in orbit around the earth, line of sight is possible only when both objects are above a plane tangent to the earth's surface. The most extreme positions for the satellites which still allow for line of sight occur when both lie in the tangent plane. These positions are defined by the following equations[5]:

$$\alpha_1 = \cos^{-1}(R_E/r_1)$$

$$\alpha_2 = \cos^{-1}(R_E/r_2)$$

The angle between the two position vectors at any point is defined as:

$$\theta = \frac{(r_1 \cdot r_2)}{|r_1||r_2|}$$

The visibility function is then defined by[5]:

$$\Gamma = \alpha_1 + \alpha_2 - \theta$$

When the value of the visibility function is positive, the satellites have line of sight. Similarly, a negative value indicates no line of sight. A value of zero is either a

rise or set time for visibility (See Figure 1). The same visibility function applies to a satellite and a ground station.

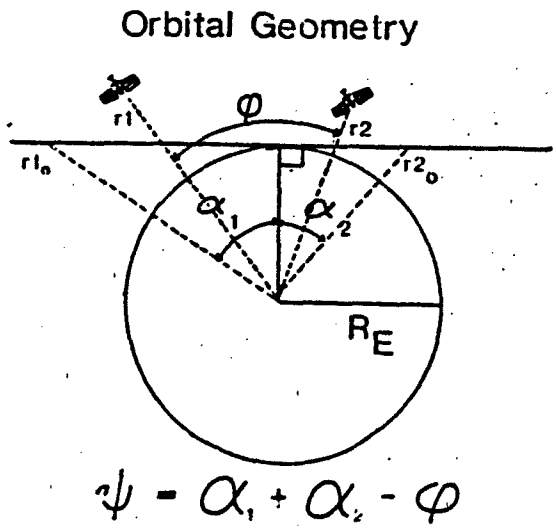


Figure 1

2.2 Basic Rise\Set Determination

The most direct method of determining visibility opportunities is small time step progression of the visibility function. At each step, the value of the visibility function is calculated. When plotted versus time, the visibility function yields a visibility waveform. When a sign change occurs in the value of the function and the wave crosses the x axis, a rise or set time is indicated. Linear interpolation is used to determine the exact time of the crossing. Although this method is legitimate, it is cumbersome and time consuming. The small time step necessary to insure the best solutions using

linear interpolation leads to large data sets and an extremely inefficient number of calculations by the computer. In order to determine the rise/set time for two satellite over a period of twenty-four hours with a time step of five seconds, more than seventeen-thousand calculations of the visibility function alone must be computed. As a method for real time solutions, this process is simply not realistic.

CHAPTER 3

THE LAWTON METHOD

3.1 The Fast Fourier Transform

In his paper, J. A. Lawton presents a method for determining visibility opportunities using a fast Fourier transform, FFT, to estimate the period of the visibility waveform[5]. The use of the FFT is in response to the need to process large quantities of data points with fewer calculations while still maintaining the accuracy of the interpolating trigonometric polynomial[4]. In his presentation, Lawton uses the FFT to select the most prominent modulus of the waveform from the equation[5]

$$C_j = \sum_{k=1}^{n} \Gamma(t_k) e^{-(2\pi i jk/n)} \qquad j = 1,2,\ldots,n$$

where

$\Gamma(t_k)$ = the visibility function at time t_k

$i = \sqrt{-1}$

n = number of data points

The value of Cj with the largest modulus, Cjmax, is then used to determine the value of the period of the waveform from the following equations[5].

$$w_{jmax} = \frac{2\pi(j_{max} - 1)}{n}$$

$$P = \frac{2\pi}{w_{jmax}}$$

Once the period of the waveform is determine, it is used in conjunction with a curve searching technique to determine the rise/set times of the objects in question.

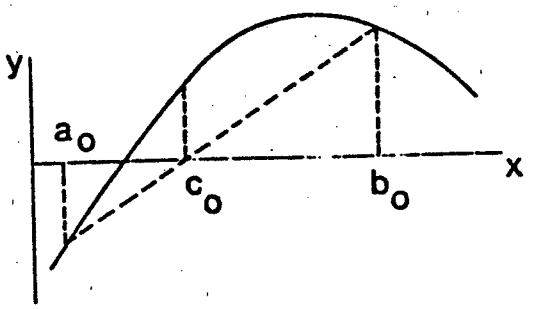
3.2 The Regula-Falsi Method of Zero Finding

The visibility waveform is first sectioned by fractions of the period determined by the FFT. The slope of the visibility function is determined in each progressive section of the wave until a local maximum value of the function is isolated between a positive and negative slope value. If the local maximum value is found to be positive, indicating line of sight is possible, then the portion of the curve in that particular section is searched for rise and set times. If the value of the visibility function is negative at the local maximum, the searching process resumes to isolate the next local maximum value[5].

Curve searching in this process is accomplished using the Regula Falsi method of zero finding. The equations is[7]:

$$c_0 = \frac{a_0 f(b_0) - b_0 f(a_0)}{f(b_0) - f(a_0)}$$

An illustration of the process is shown below in Figure 2.



$$c_o = \frac{a_o f(b_o) - b_o f(a_o)}{f(b_o) - f(a_o)}$$

Figure 2

If the value of $f(c_o)$ is zero, the search is complete. Otherwise, an iterative technique begins with reassignment of the variables occurring as follows[7]:

if $f(a_o)f(c_o) < 0$, then $a_1 = a_o$ and $b_1 = c_o$

if $f(a_o)f(c_o) > 0$, then $a_1 = c_o$ and $b_1 = b_o$

The above reassignment continues and the value of c is recalculated until $f(c_o)$ is equal to zero. In the initial process of the curve examination, this method is used to determine the time associated with a local maximum in order to determine if the value of the visibility function at the local maximum is positive or negative. In this case, no crossing of the x axis takes place and the iteration of the Regula Falsi method continues until $a_o \approx b_o$ or until the difference between a_o and b_o is sufficiently small.

Although the Lawton process is sound in the determination of rise/set times, it has the disadvantage of being limited to orbits with eccentricities less than 0.10^{5}. This is necessary to ensure a relatively periodic waveform. Very low eccentricity or nearly circular orbits produce nearly sinusoidal waves while highly elliptical orbits produce wave forms much more difficult to predict. Evidence of this can be found in the figures included with the results to this work. Aperiodic waveforms may result in inaccurate determination of the period and make curve searching a more difficult task. Additionally, this method is only applicable to evenly spaced data points[4]. Sparse data or unevenly spaced points cannot be used with the fast Fourier transform.

In his work, Lawton states this method accounted for 99.997% of the rise/set times determined by the iteration method described previously using a spherical-Earth gravity field and 99.992% of the rise/set times in an oblate-Earth gravity field.[5] He fails to state the accuracy of the rise/set times found by this method as compared to the basic iteration technique. The work in this study did not include reproduction of his results nor investigation of the accuracy of this method.

CHAPTER 4

THE PARABOLIC BLENDING TECHNIQUE

Parabolic blending is a method of curve fitting which maintains continuity of two parabolas formed from four data points. The first parabola, p(r) is defined by points 1, 2 and 3, while the second, q(s) includes points 2, 3, and 4. The parabolically blended curve is formed between points 2 and 3 (See Figure 3) and is defined by[9]

$$C(t) = (1 - t)p(r) + tq(s)$$

where $0 \leq t \leq 1$

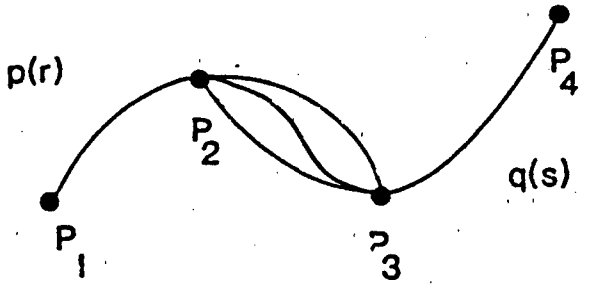


Figure 3

At t = 0, C(t) has the same slope as p(r) while at t = 1, q(s) is the influential curve. The final result of the blending is a cubic maintaining characteristics of both

parabolas. The equation of the curve is written as[1,9]

$$C(t) = a_3 t^3 + a_2 t^2 + a_1 t + a_0$$

where
$$a_0 = P_2$$
$$a_1 = -.5P_1 + .5P_3$$
$$a_2 = P_1 - 2.5P_2 + 2P_3 - .5P_4$$
$$a_3 = -.5P_1 + 1.5P_2 - 1.5P_3 + .5P_4$$

This technique differs from the cubic spline since the equation of the blended curve is independent of all other data points except for the four points used to define the two parabolas[9]. Also, parabolic blending works well with both equally and unequally space data points[1].

CHAPTER 5

FINAL ALGORITHM

The final result of this study is a computer program designed to give the user the option of determining the visibility opportunities between a combination of up to four satellites and four ground stations. More than four satellites or ground stations requires significantly more calculations and data storage. The step-by-step process of rise/set determination is detailed in the sections which follow.

5.1 Satellite Position Determination

To begin the process of determining the rise/set times for satellite-satellite or satellite-ground station visibility, it is necessary to calculate the position vector of the satellite at the start of the time of interest. This requires that six critical orbital elements be known for this calculation. They are the mean motion (n), inclination (i), eccentricity (e), longitude of the ascending node (Ω), argument of periapsis (w), and the mean anomaly (M). Although the position vector can be determined from a variety of elements, these six were chosen since they are readily known from an ephemeris of satellite information. These elements and the position of the satellite are determined with respect to the geocentric reference frame.

The first step in the determination of the position vector is the calculation of the eccentric anomaly. This is

completed through the use of the Newton-Rhapson Iteration. The equations are[2]:

$$M_n = E_n - e\ SIN(E_n)$$

$$E_{n+1} = E_n + \frac{M - M_n}{1 - e\ COS(E_n)}$$

For the first iteration, M is used in the place of E_n. When E_{n+1} is calculated, a comparison is made between E_n and E_{n+1}. When the difference is sufficiently small, the iteration is stopped. For the final computer program, the tolerance was set for a difference less than 0.000001. Convergence of the iteration may be of concern for orbits with eccentricities approaching 1.0 [2]. Once determined, the final value of E_n is used in the calculation of the true anomaly as follows[2]:

$$COS(\nu) = \frac{e - COS(E)}{e\ COS(E) - 1}$$

$$SIN(\nu) = \frac{a\sqrt{1 - e^2}}{p} \cdot SIN(E)$$

$$p = a(1 - eCOS(E))$$

Once the proper quadrant of ν is determined, the position vector is calculated in the PQW or perifocal reference frame[2].

$$\mathbf{r} = rCOS(\nu)\mathbf{P} + rSIN(\nu)\mathbf{Q}$$

$$r = \frac{a(1 - e^2)}{1 + eCOS(\nu)}$$

A coordinate transformation is then accomplished to place the position vector in the geocentric frame[3,10].

The above process determines the position vector of the satellite at a given time. Once this is accomplished, the position of the satellite must be propagated through the orbit by some time step dictated by the user. This is accomplished through the use of the following equations[1]:

$$n = n_o[1 + 1.5J_2(\frac{\sqrt{1-e^2}}{p^2})(1 - 1.5SIN^2(i))]$$

$$\Omega = -(1.5\frac{J_2}{p^2}COS(i))n$$

$$w = (1.5\frac{J_2}{p^2}[2 - 2.5SIN^2(i)])n$$

These changes in the values of the longitude of the ascending node and the argument of periapsis represent secular perturbations resulting from an aspherical earth.[6] Once these elements are propagated forward, the position vector is recalculated. In order to decrease compounding error, the position vector is propagated each iteration from the original values of Ω and w.

It is important to note other perturbing forces including atmospheric drag were not taken into account for this study. Had drag been included, secular changes in the semi-major axis, eccentricity and the inclination would have been taken into account.[6]

5.2 Ground Station Position Determination

For the determination of satellite-ground station visibility periods, the position of the ground station must be calculated. This requires the user know the following information: the year, month, day, hour, minute, and second

the simulation is to begin, the east longitude and geodetic latitude of the site, and the altitude of the site above mean sea level. This information is used in the determination of the Julian Date, the local sidereal time of the site, and the final calculation of the position vector.

This process begins with the determination of the Julian Date given the year, month, date, and time. The Julian Date is referenced to noon, 1 January 4713 B.C. The equation for the Julian Date used in this program only applies to dates between 1 March 1900 and 28 February 2100[3,10]. The equation is[3]:

$$JD = 367*Year - int\left(\frac{7(Year + int(\frac{Month+9}{12}))}{4}\right) + int\left(\frac{275*Month}{9}\right) + Day + 1721013.5 + \left|\frac{\frac{(Second + Min)}{60}}{60} + Hour\right|\Big/24$$

The Julian Date is then used to calculate the Greenwich Sidereal Time at 0 hours UT[3]:

$$\theta_{go} = 100.'4606184 + 36000.'77004T_u + '.00038793T_u^2$$

$$\text{where } T_u = \frac{\text{Julian Date} - 2451545.0}{36525.0}$$

The Greenwich Sidereal Time is then calculated according to the rotation of the earth and the universal time in terms of angles by[2]:

$$\theta_g = \theta_{go} + w_e(t - t_o)$$

Finally, the Local Sidereal Time for the site is determined by in terms of angles[2]:

$$\theta = \theta_g + \delta_r$$

From this point, the position vector of the site in the geocentric frame is calculated from[2]:

$$X = \left| \frac{a_e}{\sqrt{1 - e_e^2 SIN^2(L)}} + H \right| COS(L)$$

$$Z = \left| \frac{a_e(1 - e_e^2)}{\sqrt{1 - e_e^2 SIN^2(L)}} + H \right| SIN(L)$$

$$r = X\,COS(\theta)I + X\,SIN(\theta)J + Z\,K$$

In a manner similar to the satellite position vector propagation, the site position vector is propagated ahead with respect to the rotation of the earth and the time step indicated. It should be noted that both the satellite position vector and the ground site position vector may be calculated using either a spherical earth or an oblate earth in accordance to the users choice. If an oblate earth is chosen, the K component of both position vectors is scaled by a factor of $1/(\sqrt{1 - e_e^2})^{1.2}$.

5.3 Rise\Set Time Determination

Once the position vectors of the two objects of interest have been determined, the visibility function is calculated at each time step. Although any time step may be specified by the program user, it is suggested 25 second steps be used to allow for computer efficiency.[1] Extremely

large time steps may result in missed rise/set times. In order to insure complete evaluation of the entire time of interest, the position vectors and visibility function are calculated for times one step earlier and one step later than specified by the user. Starting at time equal to zero, parabolic blending is applied to the first four visibility function data points. The equation of the curve between points 2 and 3 is calculated. The real roots of the resulting cubic equation are computed using a closed form root solver[6]. The equations to compute the real roots of a quadratic are included in the program in the event the blended curve is a second degree polynomial or a straight line. All complex roots are ignored for this process. As stated previously, the blended curve is defined by[5]:

$$C(t) = (1 - t)P(r) + tq(s)$$

where t may take any value between 0 and 1. For this reason, only roots between and including 0 and 1 are considered.

When a real root meeting the above requirements is determined, the coefficients a_0, a_1, a_2, and a_3 are recalculated using the times corresponding to points 1, 2, 3 and 4. The roots of the original blended equation are then substituted into this second blended equation. The resulting value of the blended equation is a rise or set time. The root is then increased by a small increment and the value of the second equation is recalculated. If the value is positive, then the root in question represents a

rise time. Similarly, a negative value represents a set time.

The next blended curve is calculated between points 3 and 1 and then checked for roots. This process continues until the entire visibility waveform has been evaluated. The result is a rise/set history for two objects over a given time period.

5.4 Continuous Visibility Check

As previously mentioned, the final computer program offers the user the option of selecting up to four satellites and four ground stations for evaluation of rise/set times. It is the purpose of the continuous visibility check to evaluate the rise/set history in order to determine if constant communication is possible among the given satellites or between the ground and a constellation of satellites.

There are basically two types of communication links for satellite communications. They are forward/reverse links which occur between satellites, and uplink/downlink occurring between a satellite and the ground[11]. For two satellites, forward/reverse continuous communication is not possible if a rise or set occurs or if the satellites were not in constant communication from the beginning of the evaluation. For a three satellite constellation, at least two paths of visibility out of a possible three must be maintained at all times for constant communication to be

possible. Similarly, four satellites require three paths of visibility out of a possible six. Additionally, checks are made to determine if each ground station is in view of at least one satellite at all times for the purpose of uplink/downlink capabilities.

The continuous visibility check is accomplished by constructing a table containing every rise and set time for each possible communications path. For example, in a three satellite constellation, rise/set times are determined between satellites #1 and #2, #1 and #3, and #2 and #3. The table for this constellation would included all the rise and set times from these satellites. These rise/set opportunities represent critical times since they are the only times during the simulation when the status of visibility can change. In order to accomplish the continuous visibility check, the status of each visibility path must be determined at every rise set time. For the program, a (1) was used if two satellites were visible or experiencing a rise at a given time. Similarly, a (0) was used for a state of no visibility or a set. An example of a three satellite table is shown below.

Time (sec)	Sat's #1 & #2	Sat's #1 & #3	Sat's #2 & #3
0	1	0	1
128	1	0	0
356	0	0	1
700	0	1	0
825	0	1	0
967	1	1	0

As mentioned before, for constant communication to be maintained for a three satellite constellation, at least two paths of visibility must be available at all times. That means the sum of the (1)'s and (0)'s at a given time in the table must be greater than or equal to two. In the example above, communication is broken at 128 seconds and is not re-established until 967 seconds.

The same process is used for a four satellite constellation. In such a case, there are six possible communication paths, and the sum at any given rise or set time must be greater than or equal to three. For ground station to satellite communication, the ground station must be able to communicate with at least one satellite at any time. Therefore, the sum at each rise and set time must be greater than or equal to one for constant communication to be maintained.

CHAPTER 6

RESULTS

Attached are the results of three different runs of the final computer program attached in Appendix D. Run #1 represents a validation of the rise/set algorithm of the program. The results of this program were compared to the results contained in the research published in reference one. The initial orbital elements of the four satellites used in the program are found preceding the rise/set times. This run was achieved over a time of 86,400 seconds and a 250 second time step with a spherical earth. These results were almost identical to those achieved by the separate program created by Alfano and Negron[1]. Also included with the first run results are the rise/set values calculated using the basic iteration method mentioned earlier in the research. For this basic method, a 10,000 second time span was evaluated in 5 second intervals. The greatest variance in the compared results was less than 1 second. It should be noted the computer time to generate the visibility curve for the 10,000 second basic method between two satellites was 12 minutes, while only 3 minutes were required using the parabolic blending method over a 86,100 seconds with a 250 second time step. Run #1 also included a results using a ground station and one satellite. This run involved a 125 second time step over 86,400 seconds and an oblate earth. These results are also found in Appendix A and compare almost identically to those achieved by Alfano and Negron[1].

The basic iteration method was applied to this data as well and the results can be found in the adjoining column. The greatest variation between the parabolic blending method and the basic iteration method in this case was approximately 3 seconds.

The results of the second run are included in Appendix B. These results use the same satellites and the ground station from run #1 but all calculations involved the use of an oblate earth. As expected, the oblate earth resulted in earlier rise times and later set times[1]. Additionally, the continuous visibility check was employed in this run. Plots of the visibility function of the ground station versus each of the four satellites is included in this Appendix. Additionally, the combined plot of all four satellite-ground station functions are included as well as the six possible visibility combinations of the four satellites. These combination plots can be used to verify the results of the continuous visibility check.

Appendix C contains data resulting from the third run of the program. This run was intended to check the complete capabilities of the program by using four different satellites and four different ground stations. The run was accomplished over a time span of 86,400 seconds at a time step of 125 seconds. Data for the satellites was chosen randomly from an orbital element ephemeris of actual satellites provided by the United States Space Command. The four ground stations chosen are Space Shuttle tracking

sites. They include[5]: (=1) Kaena Point, Hawaii; (=2) Mahe Island, Indian Ocean; (=3) Thule, Greenland; (=4) Vandenburg Air Force Base, California. Again, the plots of the visibility functions are included and may be used to verify the results of the visibility check. The total run time for this case was approximately twenty minutes.

CHAPTER 7

CONCLUSIONS

While the basic iterative technique and Lawton's method are viable solutions to the rise and set time problem, the use of parabolic blending and a closed form solution has many advantages. First, parabolic blending is a flexible means to reconstruct the visibility curve. It can be used with sparse or unequally spaced data and is not restricted to near circular orbits. Second, a closed form root solver allows rise/set times to be calculated directly rather than by an iterative technique thereby reducing computer run time. The resulting timely determination of rise/set times makes this method a useful tool for use with multiple satellites and ground stations. Additionally, the inclusion of a continuous visibility check makes this program a useful tool for the investigation of satellite requirements and space mission design.

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Appendix A: Program Run #1

```
   Longitude of the Ascending Node :       0.00000000 DEG
   Argument of Periapsis           :       0.00000000 DEG

INITIAL ORBITAL ELEMENTS OF SATELLITE #2:
   Eccentricity     : 0.9363060000
   Inclination      :      64.98740000 DEG
   Mean Anomoly     :       0.00000000 DEG
   Longitude of the Ascending Node :       0.00000000 DEG
   Argument of Periapsis           :       0.00000000 DEG

INITIAL ORBITAL ELEMENTS OF SATELLITE #3:
   Eccentricity     : 0.0078742000
   Inclination      :      82.87090000 DEG
   Mean Anomoly     :       0.00000000 DEG
   Longitude of the Ascending Node :       0.00000000 DEG
   Argument of Periapsis           :       0.00000000 DEG

INITIAL ORBITAL ELEMENTS OF SATELLITE #4:
   Eccentricity     : 0.0048964000
   Inclination      :     144.64140000 DEG
   Mean Anomoly     :       0.00000000 DEG
   Longitude of the Ascending Node :       0.00000000 DEG
   Argument of Periapsis           :       0.00000000 DEG


Rise/Set Times between Satellite #1 and Satellite #2:
 83679.13091 SEC - SET

Rise/Set Times between Satellite #1 and Satellite #3:
  1450.33207 SEC - SET              1450.222816 SEC
  3965.41739 SEC - RISE             3965.454545 SEC
  6889.49771 SEC - SET              6889.599589 SEC
  9371.13568 SEC - RISE             9371.062356 SEC
 12399.31335 SEC - SET
 14774.02357 SEC - RISE
 18419.90807 SEC - SET
 20218.05526 SEC - RISE
 23546.76967 SEC - SET
 27789.37858 SEC - RISE
 30949.66914 SEC - SET
 33360.02044 SEC - RISE
 36352.15032 SEC - SET
 39814.44584 SEC - RISE
 41760.11003 SEC - SET
 44235.69347 SEC - RISE
 47181.56457 SEC - SET
 49643.34461 SEC - RISE
 52636.48892 SEC - SET
 55045.12369 SEC - RISE
 58209.92219 SEC - SET
 60445.55653 SEC - RISE
 63807.11706 SEC - SET
 67619.78663 SEC - RISE
 71227.16594 SEC - SET
 73604.36321 SEC - RISE
 76628.56161 SEC - SET
 79111.00284 SEC - RISE
 82033.93906 SEC - SET
 84549.30712 SEC - RISE
```

7692.630382 SEC - SET
9900.74196 SEC - RISE
13747.34515 SEC - SET
15662.27191 SEC - RISE
19584.87775 SEC - SET
21382.31552 SEC - RISE
25086.48497 SEC - SET
27134.82567 SEC - RISE
30810.51947 SEC - SET
32961.40487 SEC - RISE
36617.71133 SEC - SET
38842.89352 SEC - RISE
42484.01314 SEC - SET
44737.10032 SEC - RISE
48377.75627 SEC - SET
50604.70112 SEC - RISE
54259.69364 SEC - SET
56413.52413 SEC - RISE
60087.93877 SEC - SET
62158.24402 SEC - RISE
65841.04035 SEC - SET
67888.41159 SEC - RISE
71560.14873 SEC - SET
73673.39260 SEC - RISE
77319.73512 SEC - SET
79526.35809 SEC - RISE
83147.81813 SEC - SET
85412.55717 SEC - RISE

7692.630000 SEC

Rise/Set Times between Satellite #2 and Satellite #3:

2997.87843 SEC - SET
5931.10222 SEC - RISE
8939.96295 SEC - SET
11435.44659 SEC - RISE
14472.78852 SEC - SET
16877.79953 SEC - RISE
19934.36110 SEC - SET
22297.74182 SEC - RISE
25367.33066 SEC - SET
27706.27682 SEC - RISE
30785.29945 SEC - SET
33108.06577 SEC - RISE
36194.14202 SEC - SET
38505.34408 SEC - RISE
41597.01520 SEC - SET
43899.47815 SEC - RISE
46995.62990 SEC - SET
49291.29522 SEC - RISE
52391.13775 SEC - SET
54681.30707 SEC - RISE
57784.28440 SEC - SET
60069.96329 SEC - RISE
63175.51700 SEC - SET
65457.45070 SEC - RISE
68565.29108 SEC - SET
70844.04327 SEC - RISE
73953.83055 SEC - SET
76229.83962 SEC - RISE
79341.37564 SEC - SET
81615.05419 SEC - RISE
84728.03935 SEC - SET

2997.887324 SEC
5931.141593 SEC
8939.946429 SEC

13412.02208 SEC - RISE
17536.54531 SEC - SET
19673.27556 SEC - RISE
23787.20492 SEC - SET
25923.63498 SEC - RISE
30032.62420 SEC - SET
32169.13711 SEC - RISE
36275.30607 SEC - SET
38411.96192 SEC - RISE
42516.36090 SEC - SET
44653.14374 SEC - RISE
48756.32667 SEC - SET
50893.22948 SEC - RISE
54995.50864 SEC - SET
57132.55012 SEC - RISE
61234.12410 SEC - SET
63371.29703 SEC - RISE
67472.30883 SEC - SET
69609.58623 SEC - RISE
73710.14286 SEC - SET
75847.56839 SEC - RISE
79947.69212 SEC - SET
82085.26989 SEC - RISE
86185.16424 SEC - SET

Rise/Set Times between Satellite #3 and Satellite #4:

728.00260 SEC - SET	728.253012 SEC
2144.97084 SEC - RISE	2145.755968 SEC
3508.89011 SEC - SET	3508.638444 SEC

34217.02408 SEC - RISE
35246.56198 SEC - SET
36889.15759 SEC - RISE
38274.52867 SEC - SET
39624.21934 SEC - RISE
41174.78140 SEC - SET
42839.99372 SEC - RISE
43670.74866 SEC - SET
72091.70409 SEC - RISE
72474.06899 SEC - SET
74570.33847 SEC - RISE
75735.76905 SEC - SET
77179.52589 SEC - RISE
78783.75035 SEC - SET
80215.31302 SEC - RISE
81418.26446 SEC - SET
83415.21845 SEC - RISE
83937.59649 SEC - SET

THE LOCATION OF GROUND STATION =1
EAST LONGITUDE: 0.000000
GEODETIC LATITUDE: 39.000000
ALTITUDE ABOVE THE EARTH ELLIPSOID: 2.900000

INITIAL ORBITAL ELEMENTS OF SATELLITE =1:
Eccentricity : 0.0078742000
Inclination : 82.87090000 DEG
Mean Anomoly : 0.00000000 DEG
Longitude of the Ascending Node : 0.00000000 DEG
Argument of Periapsis : 0.00000000 DEG

RISE AND SET TIMES BETWEEN GROUND STATION =1 AND SATELLITE =1:

366.33816 SEC - RISE	366.4128596 SEC	
793.74516 SEC - SET	793.3902878 SEC	
5973.86027 SEC - RISE	5972.4175820 SEC	
6041.56945 SEC - SET	6044.6470590 SEC	
39460.44479 SEC - RISE		
39949.95608 SEC - SET		
44907.37075 SEC - RISE		
45292.93512 SEC - SET		
86261.28564 SEC - RISE		

Appendix B: Program Run #2

```
Rise/Set Times between Satellite #1 and Satellite #3:
  1460.52842 SEC - SET
  3954.59411 SEC - RISE
  6901.04371 SEC - SET
  9357.44428 SEC - RISE
 12414.55102 SEC - SET
 14750.81501 SEC - RISE
 18432.45195 SEC - SET
 20069.68746 SEC - RISE
 25578.36179 SEC - SET
 27770.73291 SEC - RISE

Rise/Set Times between Satellite #1 and Satellite #4:
  1807.91575 SEC - SET
  4069.37257 SEC - RISE
  7695.00886 SEC - SET
  9900.04560 SEC - RISE
 13549.39377 SEC - SET
 15662.26623 SEC - RISE
 19335.91349 SEC - SET
 21381.74668 SEC - RISE
 25066.47341 SEC - SET
 27132.76382 SEC - RISE

Rise/Set Times between Satellite #2 and Satellite #3:
  2997.97685 SEC - SET
  5924.02061 SEC - RISE
  8944.66759 SEC - SET
 11427.18627 SEC - RISE
 14479.19061 SEC - SET
 16868.98772 SEC - RISE
 19941.62420 SEC - SET
 22288.63982 SEC - RISE
 25375.13704 SEC - SET
 27696.99684 SEC - RISE

Rise/Set Times between Satellite #2 and Satellite #4:
  4932.42624 SEC - SET
  7104.92257 SEC - RISE
 11273.16055 SEC - SET
 13407.13572 SEC - RISE
 17537.31159 SEC - SET
 19669.08990 SEC - RISE
 23788.08220 SEC - SET
 25919.79045 SEC - RISE

Rise/Set Times between Satellite #3 and Satellite #4:
   738.80937 SEC - SET
  2137.92179 SEC - RISE
  3516.84185 SEC - SET

*
```

(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS COMMUNICATIONS.)
Communications broken at 3516.84185 SEC
Communications re-established at 3954.59411 SEC
Communications broken at 8944.66759 SEC
Communications re-established at 9357.44428 SEC
Communications broken at 14479.19061 SEC
Communications re-established at 14750.81501 SEC
Communications broken at 19335.91349 SEC
Communications re-established at 19669.08990 SEC
Communications broken at 19941.62420 SEC
Communications re-established at 20069.68746 SEC
Communications broken at 25375.13704 SEC
Communications re-established at 27132.76382 SEC

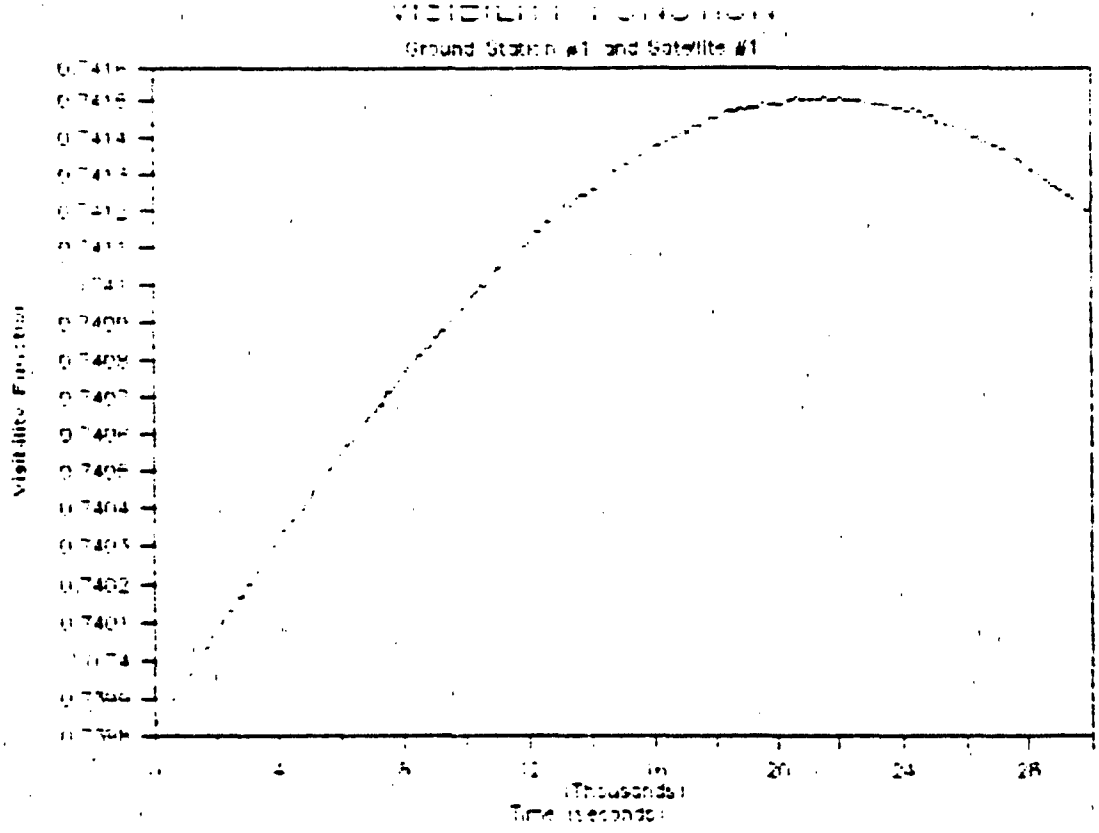
```
RISE AND SET TIMES BETWEEN GROUND STATION #1 AND      SATELLITE #1:

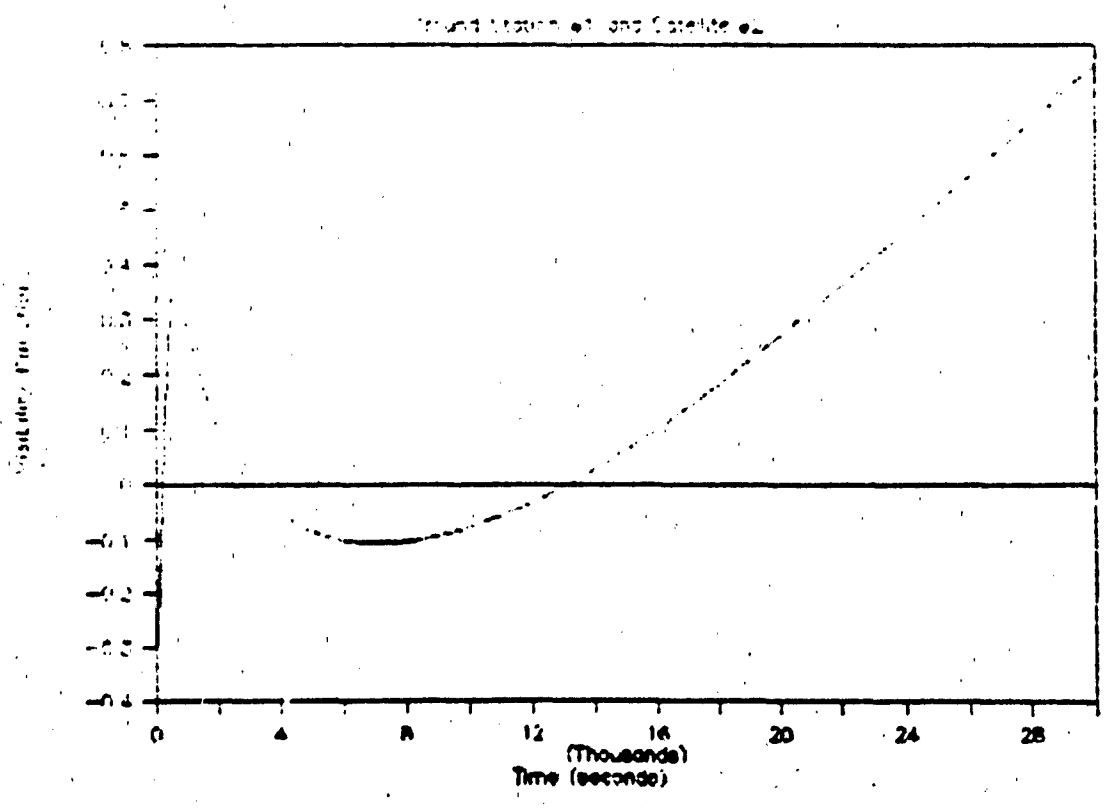
RISE AND SET TIMES BETWEEN GROUND STATION #1 AND      SATELLITE #2:
   200.76093 SEC - RISE
  3060.09662 SEC - SET
 13147.67 3 SEC - RISE

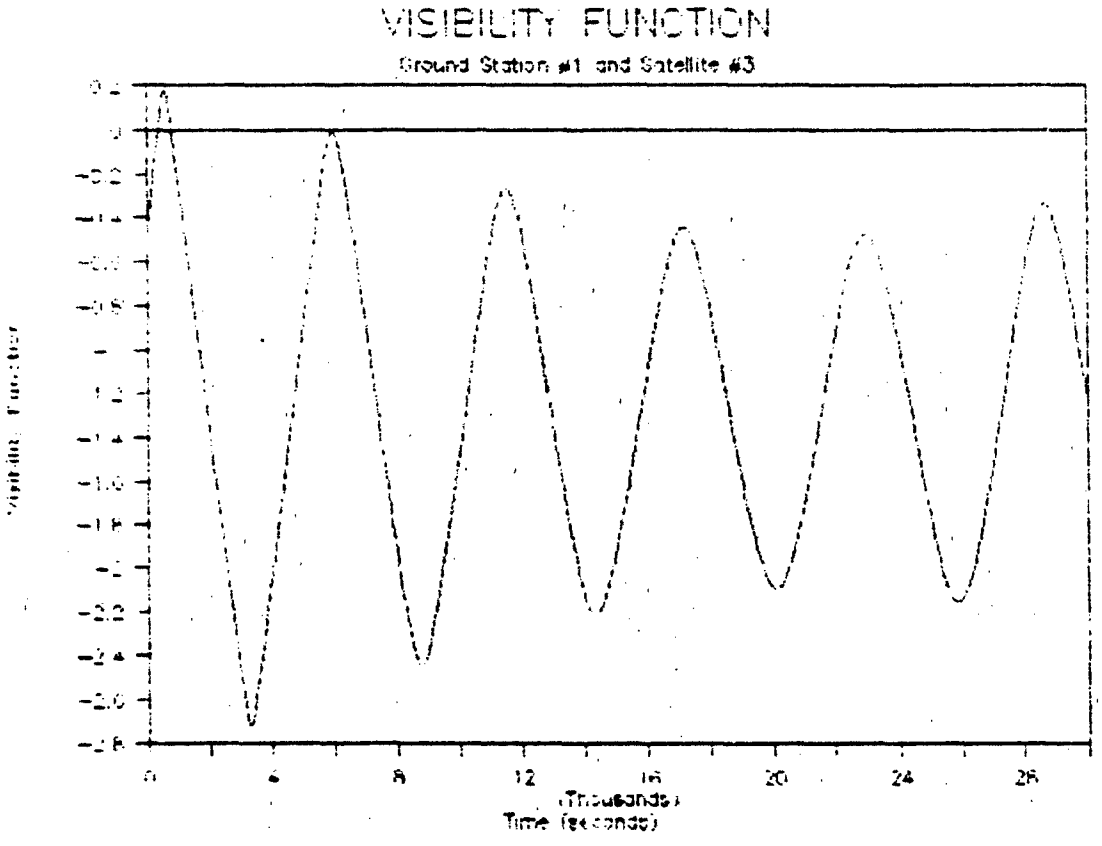
RISE AND SET TIMES BETWEEN GROUND STATION #1 AND      SATELLITE #3:
   366.33816 SEC - RISE
   793.74516 SEC - SET
  5973.86027 SEC - RISE
  6041.56945 SEC - SET

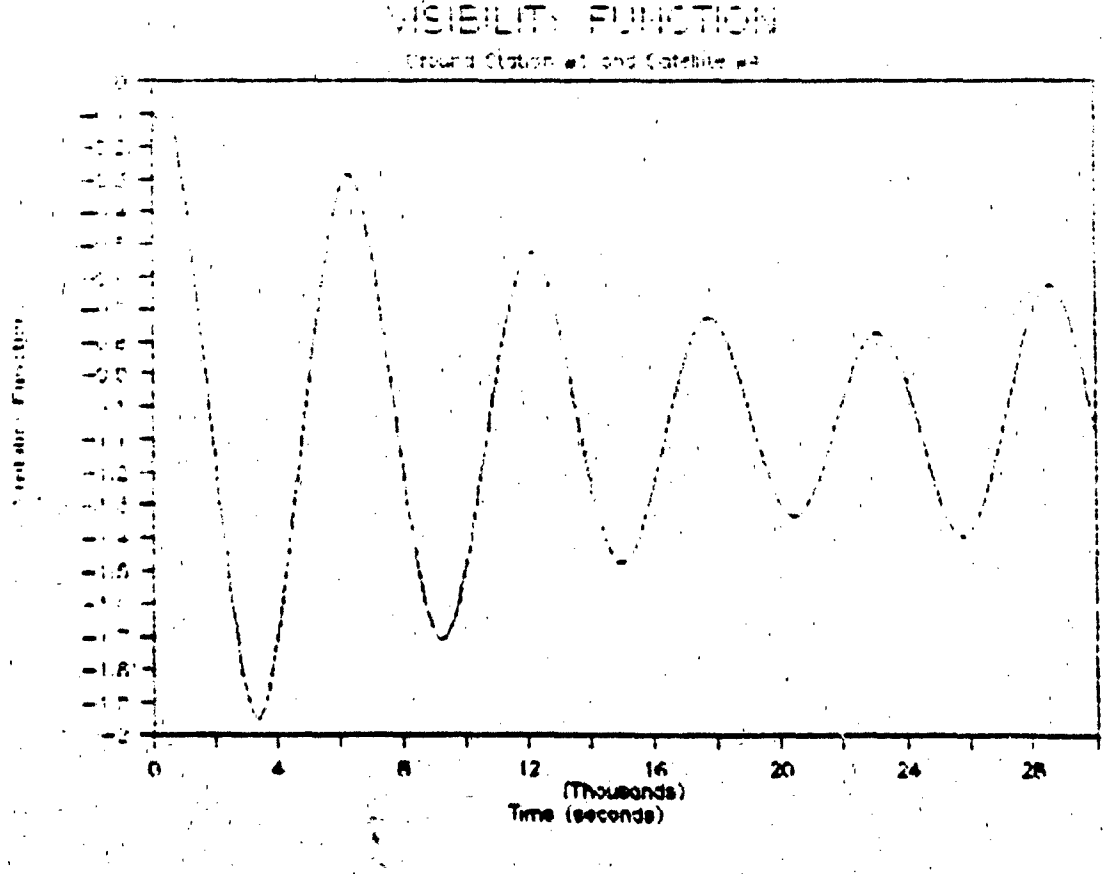
RISE AND SET TIMES BETWEEN GROUND STATION #1 AND      SATELLITE #4:

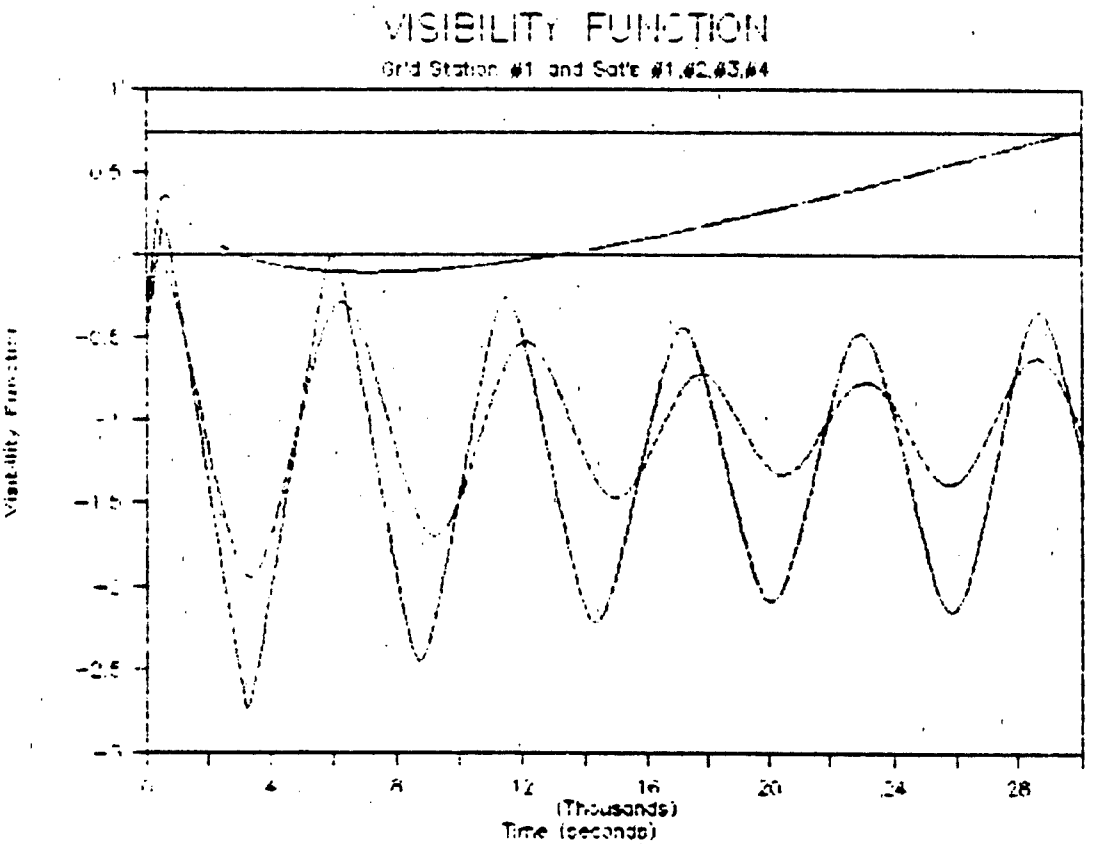
COMMUNICATIONS STATUS BETWEEN GROUND STATION #1 AND   THE FOUR GIVEN SATELLITES:
(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS    COMMUNICATIONS.)
```

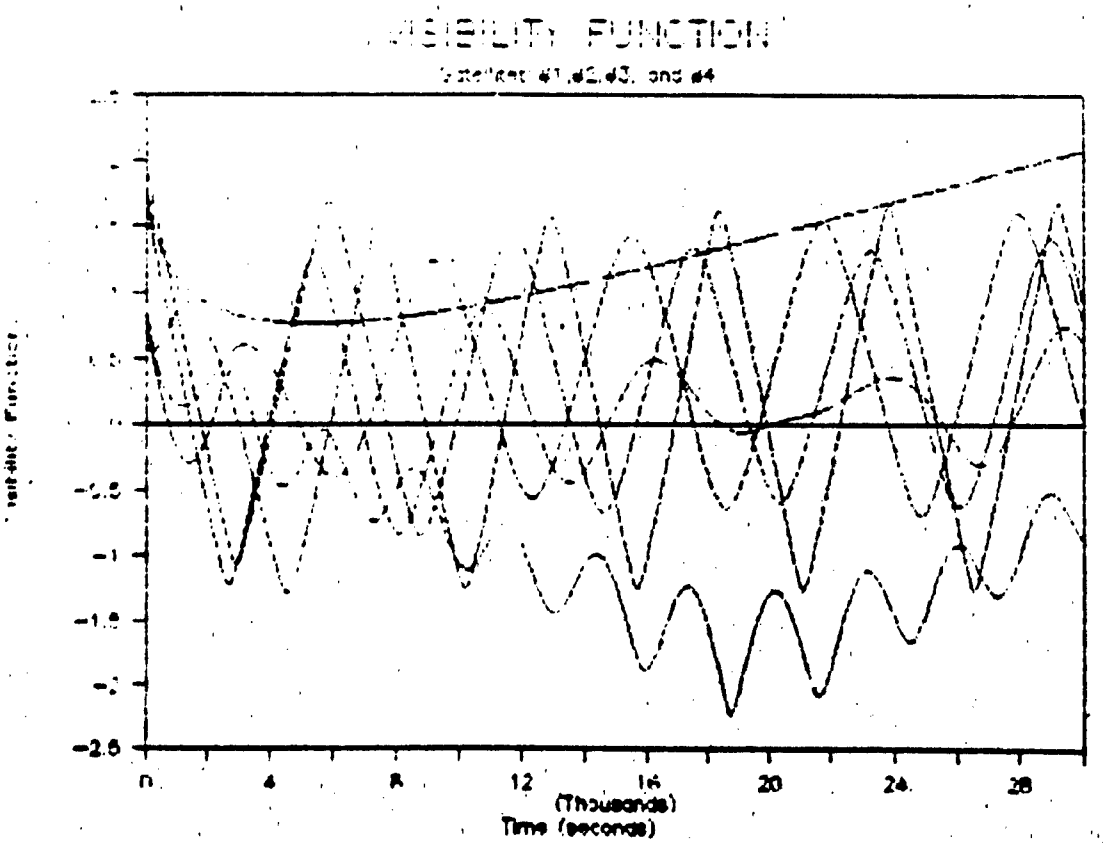

Ground Station #1 and Satellite #1
Visibility Function
0.7415
0.7414
0.7413
0.7412
0.7411
0.741
0.7409
0.7408
0.7407
0.7406
0.7405
0.7404
0.7403
0.7402
0.7401
0.74
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)


0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)


VISIBILITY FUNCTION
Ground Station #1 and Satellite #3
Visibility Function
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)


VISIBILITY FUNCTION
Visibility Function
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)


VISIBILITY FUNCTION
Grid Station #1 and Sat's #1,#2,#3,#4
Visibility Function
0.5
-0.5
-1
-1.5
-2
-2.5
-3
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)


VISIBILITY FUNCTION
Satellites #1,#2,#3, and #4
Visibility Function
0.5
-0.5
-1
-1.5
-2
-2.5
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)

Appendix C: Program Run #3

TIME FOR BEGINNING THE SIMULATION: 17:30.45

THE LOCATION OF GROUND STATION #1
EAST LONGITUDE: 201.735000
GEODETIC LATITUDE: 21.571500
ALTITUDE ABOVE THE EARTH ELLIPSOID: 0.000000

THE LOCATION OF GROUND STATION #2
EAST LONGITUDE: 55.480000
GEODETIC LATITUDE: -4.669900
ALTITUDE ABOVE THE EARTH ELLIPSOID: 0.000000

THE LOCATION OF GROUND STATION #3
EAST LONGITUDE: 291.400000
GEODETIC LATITUDE: 76.508200
ALTITUDE ABOVE THE EARTH ELLIPSOID: 0.000000

THE LOCATION OF GROUND STATION #4
EAST LONGITUDE: 239.498300
GEODETIC LATITUDE: 34.823100
ALTITUDE ABOVE THE EARTH ELLIPSOID: 0.000000

INITIAL ORBITAL ELEMENTS OF SATELLITE #1:
Eccentricity : 0.0668128000
Semi-major Axis : 117819.33914850 KM
Inclination : 57.35000000 DEG
Mean Anomoly : 274.64810000 DEG
Longitude of the Ascending Node : 65.63070000 DEG
Argument of Periapsis : 79.11000000 DEG

INITIAL ORBITAL ELEMENTS OF SATELLITE #2:
Eccentricity : 0.0003109000
Semi-major Axis : 42164.58832806 KM
Inclination : 0.00990000 DEG
Mean Anomoly : 132.80340000 DEG
Longitude of the Ascending Node : 227.28640000 DEG
Argument of Periapsis : 359.92590000 DEG

INITIAL ORBITAL ELEMENTS OF SATELLITE #3:
Eccentricity : 0.0145072000
Semi-major Axis : 7496.14095141 KM
Inclination : 90.26190000 DEG
Mean Anomoly : 246.05610000 DEG
Longitude of the Ascending Node : 107.70380000 DEG
Argument of Periapsis : 115.56590000 DEG

INITIAL ORBITAL ELEMENTS OF SATELLITE #4:
Eccentricity : 0.0531098000
Semi-major Axis : 7210.27162153 KM
Inclination : 66.05630000 DEG
Mean Anomoly : 245.56390000 DEG
Longitude of the Ascending Node : 108.27480000 DEG
Argument of Periapsis : 119.97980000 DEG

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Rise/Set Times between Satellite #1 and Satellite #3:
  2096.74276 SEC - SET
  3749.77870 SEC - RISE
  8657.22758 SEC - SET
 10396.52711 SEC - RISE
 15206.50054 SEC - SET
 17033.58950 SEC - RISE
 21747.79647 SEC - SET
 23658.24122 SEC - RISE
 28283.42317 SEC - SET

Rise/Set Times between Satellite #1 and Satellite #4:
  1307.23847 SEC - SET
  3272.45823 SEC - RISE
  7507.23028 SEC - SET
  9472.56593 SEC - RISE
 13707.25247 SEC - SET
 15679.29431 SEC - RISE
 19906.64430 SEC - SET
 21891.90738 SEC - RISE
 26104.35521 SEC - SET
 28109.37531 SEC - RISE

Rise/Set Times between Satellite #2 and Satellite #3:
  9589.46045 SEC - SET
  9952.64793 SEC - RISE
 15090.00549 SEC - SET
 17190.80137 SEC - RISE
 21406.02460 SEC - SET
 23759.34470 SEC - RISE
 27853.51599 SEC - SET

Rise/Set Times between Satellite #2 and Satellite #4:
   146.81313 SEC - SET
  2048.36595 SEC - RISE
  7176.32283 SEC - SET
  9093.61752 SEC - RISE
 13570.46290 SEC - SET
 15790.10429 SEC - RISE
 19826.60084 SEC - SET
 22187.89728 SEC - RISE
 26069.57330 SEC - SET
 28469.81596 SEC - RISE

Rise/Set Times between Satellite #3 and Satellite #4:
 13706.79928 SEC - SET
 16641.32575 SEC - RISE
 18745.74240 SEC - SET

COMMUNICATIONS STATUS BETWEEN SATELLITE #1, #2, #3, AND    #4:
(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS    COMMUNICATIONS.)
Communications broken at  15090.00549 SEC
Communications re-established at  15790.10429 SEC
Communications broken at  21406.02460 SEC
Communications re-established at  22187.89728 SEC
Communications broken at  27853.51599 SEC
Communications re-established at  28109.37531 SEC
Communications broken at  28283.42317 SEC
Communications re-established at  28469.81596 SEC

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 27189.14692 SEC - SET

RISE AND SET TIMES BETWEEN GROUND STATION #1 AND      SATELLITE #2:

RISE AND SET TIMES BETWEEN GROUND STATION #1 AND      SATELLITE #3:
  6659.66079 SEC - RISE
  7205.64965 SEC - SET
 12742.74680 SEC - RISE
 13876.25363 SEC - SET
 19342.09950 SEC - RISE
 20205.80586 SEC - SET

RISE AND SET TIMES BETWEEN GROUND STATION #1 AND      SATELLITE #4:
 12011.00325 SEC - RISE
 12888.92281 SEC - SET
 18219.91633 SEC - RISE
 19170.28556 SEC - SET

COMMUNICATIONS STATUS BETWEEN GROUND STATION #1 AND   THE FOUR GIVEN SATELLITES:
(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS    COMMUNICATIONS.)

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RISE AND SET TIMES BETWEEN GROUND STATION #2 AND      SATELLITE #1:
 18845.80416 SEC - RISE

RISE AND SET TIMES BETWEEN GROUND STATION #2 AND      SATELLITE #2:

RISE AND SET TIMES BETWEEN GROUND STATION #2 AND      SATELLITE #3:
  2776.71326 SEC - RISE
  3809.60547 SEC - SET
  9232.43874 SEC - RISE
 10218.11934 SEC - SET

RISE AND SET TIMES BETWEEN GROUND STATION #2 AND      SATELLITE #4:
  2575.55488 SEC - RISE
  3233.90819 SEC - SET
  8752.25542 SEC - RISE
  9560.57871 SEC - SET

COMMUNICATIONS STATUS BETWEEN GROUND STATION #2 AND   THE FOUR GIVEN SATELLITES:
(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS    COMMUNICATIONS.)
Communications broken at    0.000000000000000
Communications re-established at     2575.55488485389
Communications broken at     3809.60546671516
Communications re-established at     8752.25541685105
Communications broken at     10218.1193431246
Communications re-established at     18845.8041619931
```

RISE AND SET TIMES BETWEEN GROUND STATION #3 AND SATELLITE #2:

RISE AND SET TIMES BETWEEN GROUND STATION #3 AND SATELLITE #3:
863.15409 SEC - RISE
1929.46674 SEC - SET
7439.15083 SEC - RISE
8459.80178 SEC - SET
14032.54055 SEC - RISE
15028.79748 SEC - SET
20602.42738 SEC - RISE
21618.43278 SEC - SET
27132.37091 SEC - RISE
28188.78822 SEC - SET

RISE AND SET TIMES BETWEEN GROUND STATION #3 AND SATELLITE #4:
994.31344 SEC - RISE
1550.61962 SEC - SET
7128.82589 SEC - RISE
7759.49949 SEC - SET
13314.48646 SEC - RISE
13955.25665 SEC - SET
19524.67234 SEC - RISE
20130.86382 SEC - SET
25748.10806 SEC - RISE
26262.61775 SEC - SET

COMMUNICATIONS STATUS BETWEEN GROUND STATION #3 AND THE FOUR GIVEN SATELLITES:
(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS COMMUNICATIONS.)
Communications broken at 0.000000000000000
Communications re-established at 863.154088411520
Communications broken at 1929.46674256308
Communications re-established at 7128.82589091173
Communications broken at 8459.80177798542
Communications re-established at 13314.4864571971
Communications broken at 13955.2566531969
Communications re-established at 14032.5405513214
Communications broken at 15028.7974810107
Communications re-established at 19524.6723377486
Communications broken at 20130.8638220675
Communications re-established at 20602.4273755799
Communications broken at 21618.4327784578
Communications re-established at 25748.1080570079
Communications broken at 26262.6177511727
Communications re-established at 27132.3709121300
Communications broken at 28188.7882164166

*

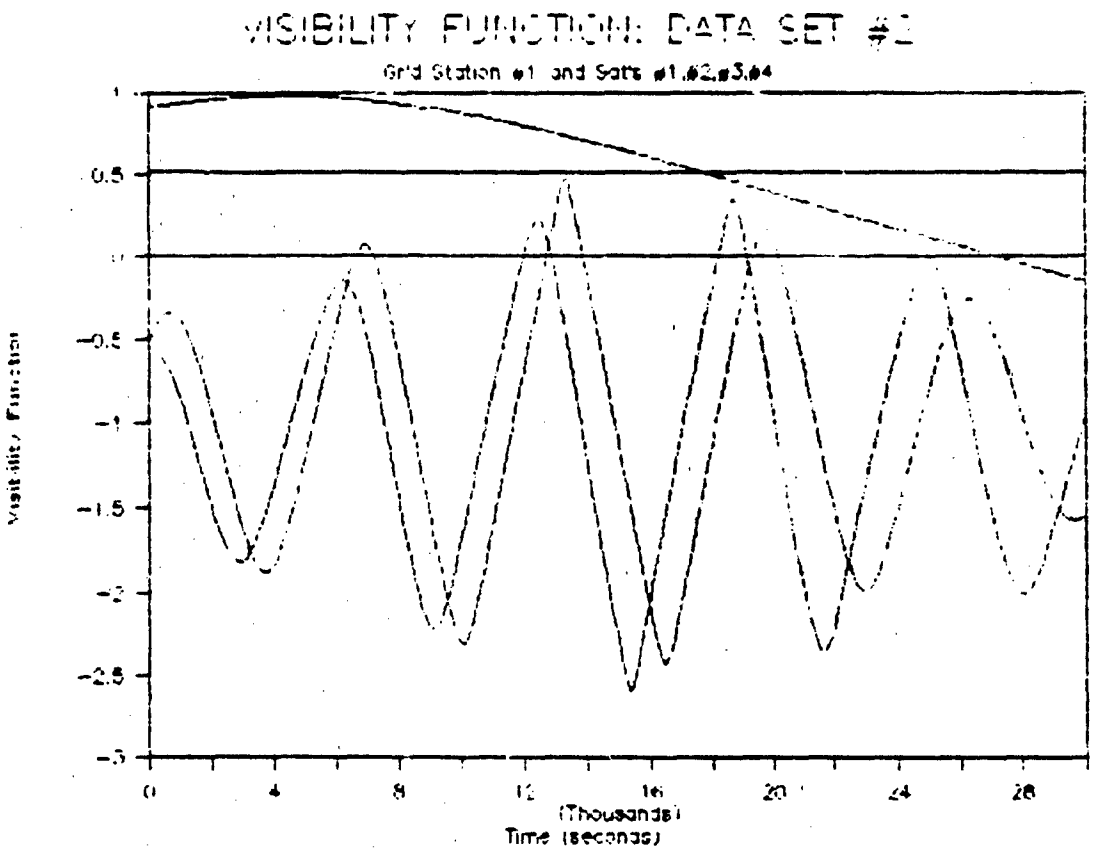
```
RISE AND SET TIMES BETWEEN GROUND STATION #4 AND      SATELLITE #1:
 15864.12078 SEC - SET

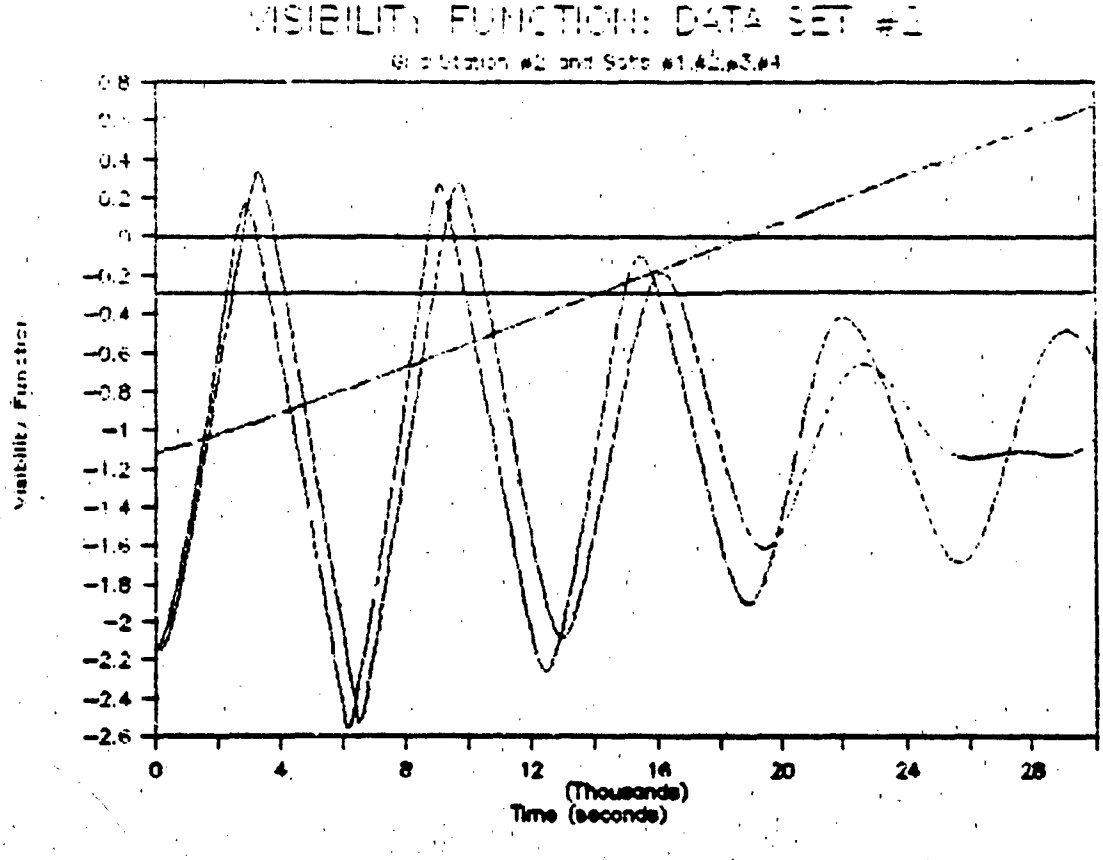
RISE AND SET TIMES BETWEEN GROUND STATION #4 AND      SATELLITE #2:

RISE AND SET TIMES BETWEEN GROUND STATION #4 AND      SATELLITE #3:
   160.74120 SEC - RISE
  1145.77540 SEC - SET
  6518.52238 SEC - RISE
  7628.58607 SEC - SET
 13356.74253 SEC - RISE
 13863.55253 SEC - SET

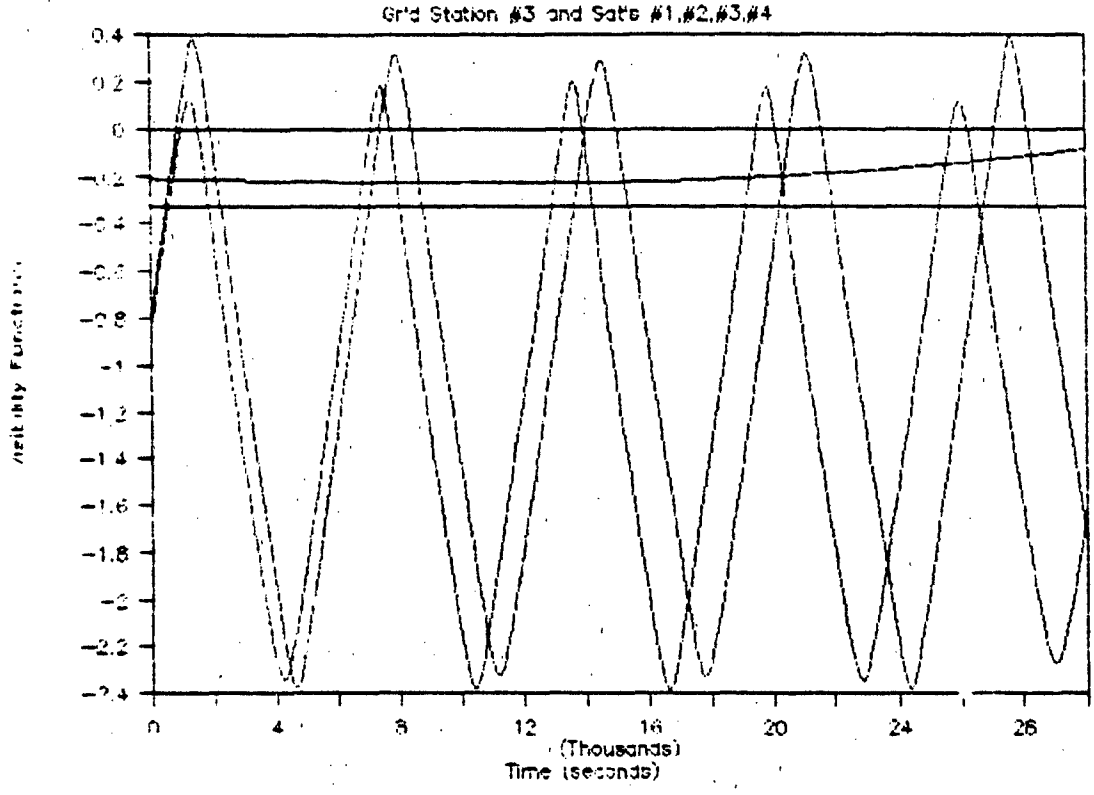
RISE AND SET TIMES BETWEEN GROUND STATION #4 AND      SATELLITE #4:
  6188.38578 SEC - RISE
  7079.50299 SEC - SET
 12477.73425 SEC - RISE
 13319.74884 SEC - SET
 19231.12443 SEC - RISE
 19321.51031 SEC - SET

COMMUNICATIONS STATUS BETWEEN GROUND STATION #4 AND   THE FOUR GIVEN SATELLITES:
(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS    COMMUNICATIONS.)
Communications broken at      15864.1207815275
Communications re-established at      19231.1244274451
Communications broken at      19321.5103139570
```

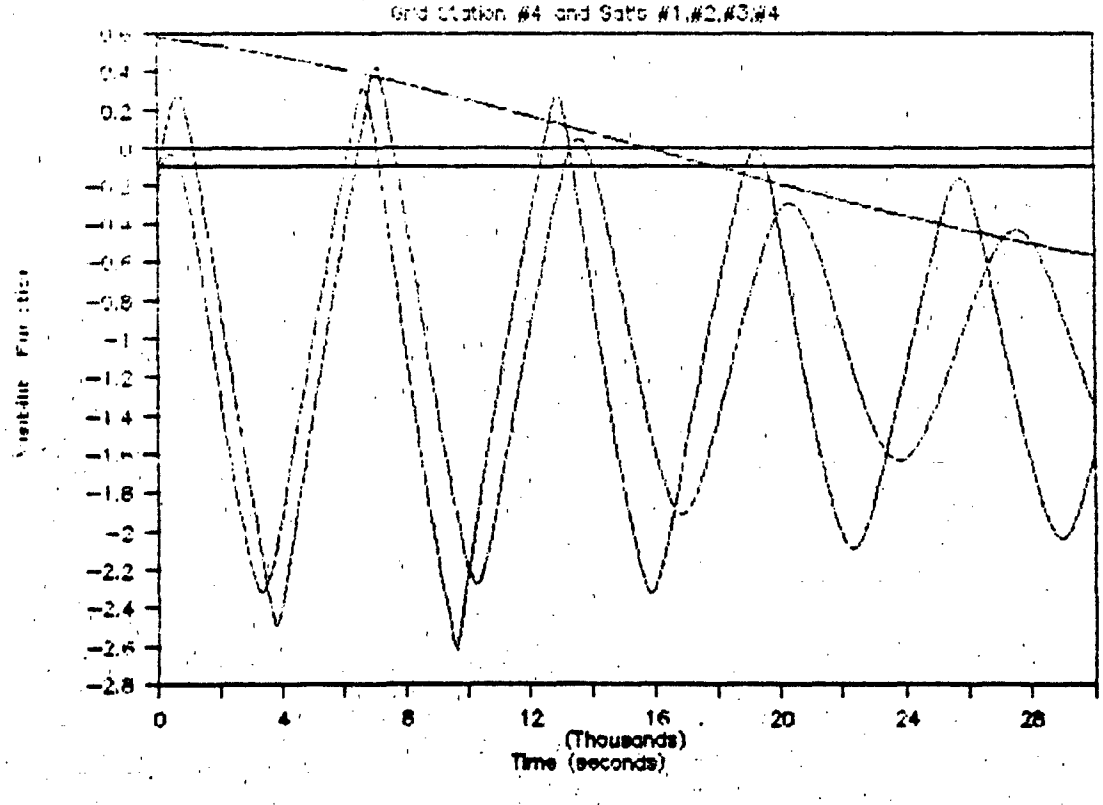

VISIBILITY FUNCTION: DATA SET #1
Grid Station #1 and Sats #1,#2,#3,#4
0.5
-0.5
-1
-1.5
-2
-2.5
-3
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)

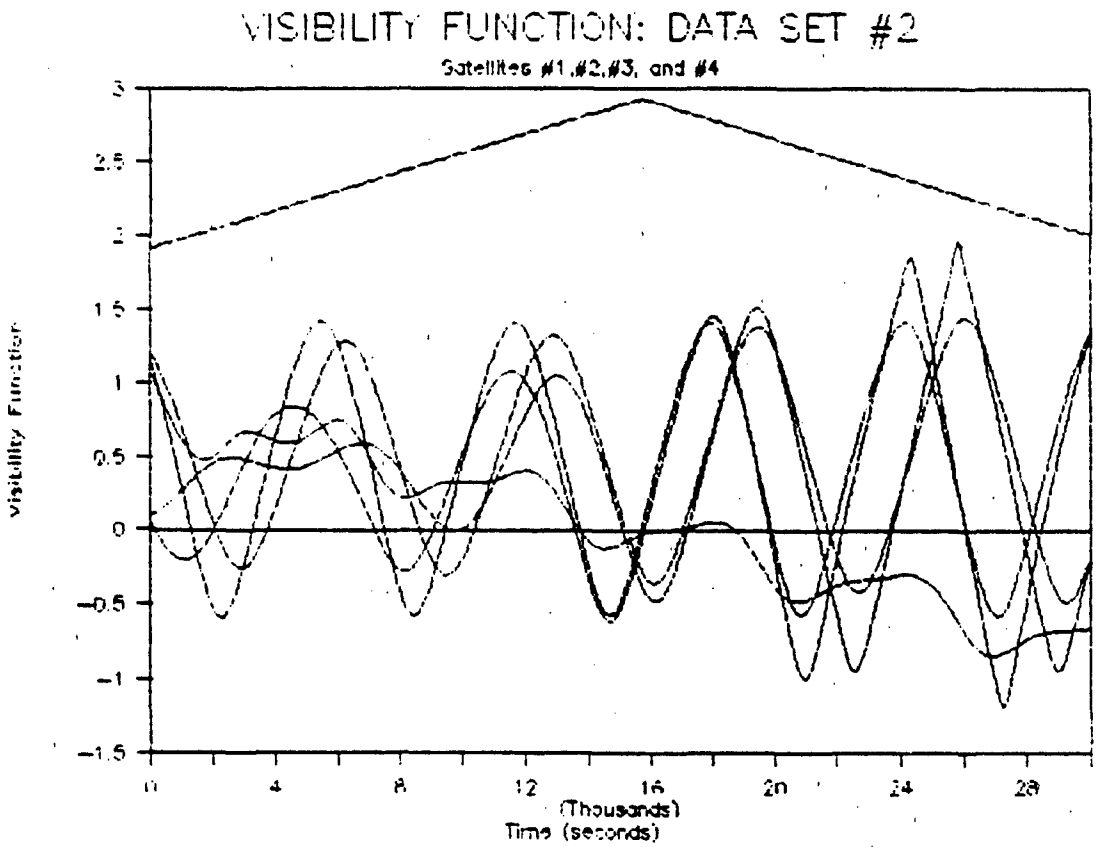

VISIBILITY FUNCTION: DATA SET #1
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)

VISIBILITY FUNCTION: DATA SET #2



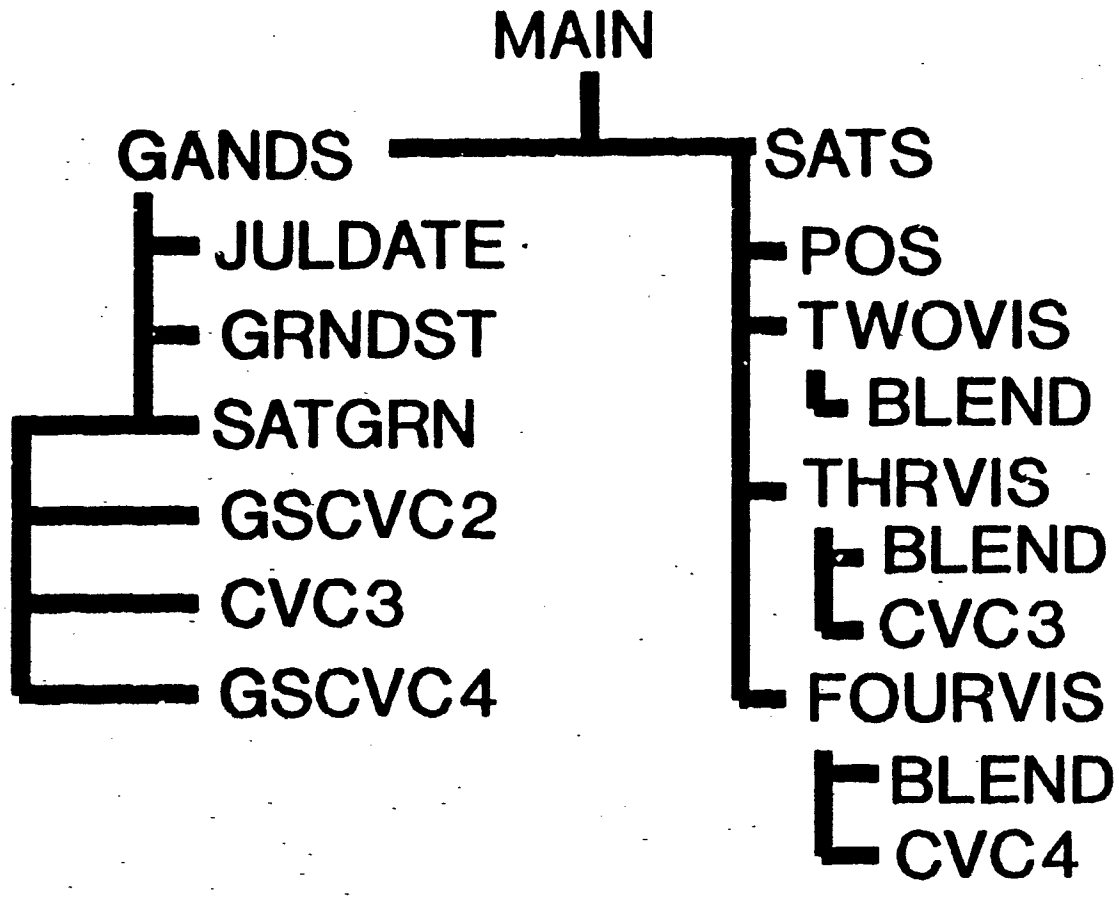
VISIBILITY FUNCTION: DATA SET #2




VISIBILITY FUNCTION: DATA SET #2
Satellites #1,#2,#3, and #4
Visibility Function
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
4
8
12
16
20
24
28
(Thousands)
Time (seconds)

Appendix D: Program Listing

PROGRAM TREE



```
*   PURPOSE:  This program determines rise set times for inview      *
*             periods for satellite to satellite or satellite to     *
*             ground station viewing.  This program is designed      *
*             to accommodate up to four satellites and as many       *
*             ground station.  The following information is          *
*             necessary to be able to use the program:               *
*                Satellite Orbit:  1) Eccentricity                   *
*                                  2) Length of Semi major Axis      *
*                                  3) Inclination                    *
*                                  4) Mean Anomoly                   *
*                                  5) Longitude of the Ascending     *
*                                     Node                           *
*                                  6) Argument of Periapsis          *
*                Ground Station:   1) Julian Date in Question        *
*                                  2) East Longitude                 *
*                                  3) Height Above Sea Level         *
*             Other required information includes the amount of time *
*             of interest and the desired time step for incrementa-  *
*             tion.  The program is not limited to any particular    *
*             type of orbit.  *changed to mean motion                *
*                                                                    *
*  VARIABLES:                                                        *
*      CHOICE - the number of satellites indicated by the user       *
*      ELIP2  - square of the eccentricity of the earth              *
*      NUM    - the number of ground stations indicated by the user  *
*      S2TU   - converts SEC to TU; includes the steps size          *
*      SIZE   - step size                (SEC)                       *
*      STEPS  - number of steps                                      *
*      TIME   - total time of interest  (MIN)                        *
*      YORN   - yes or no response                                   *
*      SOROB  - spherical or oblate earth                            *
**********************************************************************
      REAL*8  ELIP2,TIME,SIZE,S2TU
      INTEGER CHOICE,NUM,SOROB,STEPS,YORN

      OPEN(UNIT=25,FILE='RISESET.DAT',STATUS='NEW')
**********************************************************************
*                       USERS CHOICE                                 *
**********************************************************************
      WRITE(*,*)'     This program is designed to determine rise and'
      WRITE(*,*)'set times for satellite to satellite viewing as well'
      WRITE(*,*)'as satellite to ground station viewing.  If you choose'
      WRITE(*,*)'to enter ground stations, satellite to satellite rise'
      WRITE(*,*)'and set times will be computed as well as satellite'
      WRITE(*,*)'to ground station rise and set times.'
      WRITE(*,*)
    1 WRITE(*,*)'    Are you interested in satellite to ground station'
      WRITE(*,*)'viewing?      1)Yes      2)No '
      WRITE(*,*)' =====> '
      READ(*,*,ERR=1)YORN

      IF (YORN.GT.2.OR.YORN.LT.1) THEN
         WRITE(*,*)'Your selection was not a valid response. Please'
         WRITE(*,*)'select again.'
         GOTO 5
      ENDIF

    2 WRITE(*,*)'Are you interested in modeling a spherical earth'
      WRITE(*,*)'or an oblate earth?   1)Spherical   2)Oblate'
      WRITE(*,*)' =====> '
      READ(*,*,ERR=2)SOROB
```

```
      ELIP2 = 0.0
      ELSE IF (SOROB.EQ.2) THEN
         ELIP2 = 0.00669437999013D0
      ENDIF
*************************************************************************
*   The following prompts the user to enter the values of the           *
*   time of interest and the step size.                                 *
*************************************************************************
    5 WRITE(*,*)'What is the total time of interest (in minutes) ==> '
      READ(*,*,ERR=5)TIME
      WRITE(*,*)'The time entered above will be evaluated in steps.'
      WRITE(*,*)'The choice of step size is up to you; however, it '
      WRITE(*,*)'should be noted that step sizes too large may result'
      WRITE(*,*)'in missed rise and set times.  A suggested step size'
      WRITE(*,*)'is 250 seconds.'
    6 WRITE(*,*)'What is the step size of interest (in secs) ==> '
      READ(*,*,ERR=6)SIZE

      TIME  = TIME*60.0D0
      STEPS = DINT(TIME/SIZE)
      S2TU  = SIZE/806.8103818D0
*************************************************************************
*   The following prompts the user to enter the number of ground        *
*   stations and/or satellites he/she desires                           *
*************************************************************************
      IF (YORN.EQ.1) THEN
    8    WRITE(*,*)'How many ground stations do you desire.  Please'
         WRITE(*,*)'make your selection from below.'
         WRITE(*,*)'     1) 1 Ground Station'
         WRITE(*,*)'     2) 2 Ground Stations'
         WRITE(*,*)'     3) 3 Ground Stations'
         WRITE(*,*)'     4) 4 Ground Stations'
         WRITE(*,*)'====> '
         READ(*,*,ERR=8)NUM

         IF (NUM.LT.1.OR.NUM.GT.4) THEN
            WRITE(*,*)'Your entry was not valid.  Please reenter the'
            WRITE(*,*)'number of ground stations.'
            GOTO 8
         ENDIF

    9    WRITE(*,*)'How many satellites do you wish to enter?  Please'
         WRITE(*,*)'make your selection from below.'
         WRITE(*,*)'     1) 1 Satellite '
         WRITE(*,*)'     2) 2 Satellites'
         WRITE(*,*)'     3) 3 Satellites'
         WRITE(*,*)'     4) 4 Satellites'
         WRITE(*,*)'====> '
         READ(*,*,ERR=9)CHOICE
         CALL GANDS(CHOICE,ELIP2,NUM,S2TU,SIZE,STEPS)

      ELSE
   10    WRITE(*,*)'Please make a selection for the type of viewing'
         WRITE(*,*)'you prefer:'
         WRITE(*,*)'     1) 2 Satellite Viewing'
         WRITE(*,*)'     2) 3 Satellite Viewing'
         WRITE(*,*)'     3) 4 Satellite Viewing'
         WRITE(*,*)'====>  '
         READ(*,*,ERR=10)CHOICE
         NUM = 0

         IF (CHOICE.LT.1.OR.CHOICE.GT.3) THEN
            WRITE(*,*)'Your choice was not valid. Please re-enter'
```

```
      -----
      CALL SATS(CHOICE,ELIP2,S2TU,SIZE,STEPS)

      ENDIF

    CLOSE(UNIT=10)
    CLOSE(UNIT=11)
    CLOSE(UNIT=12)
    CLOSE(UNIT=13)
    CLOSE(UNIT=14)
    CLOSE(UNIT=15)
    CLOSE(UNIT=25)
    CLOSE(UNIT=31)
    CLOSE(UNIT=32)
    CLOSE(UNIT=33)
    CLOSE(UNIT=34)

    END
*
```

```
*                                                                     *
*   PURPOSE:  The purpose of this subroutine is to coordinate the     *
*             determination of rise/set times between satellites      *
*             and ground stations.                                    *
*                                                                     *
*   VARIABLES:                                                        *
*     INPUT:                                                          *
*       CHOICE - the number of satellites indicated by the user       *
*       NUM    - the number of ground stations indicated by the user  *
*       S2TU   - converts SEC to TU                                   *
*       SIZE   - step size (SEC)                                      *
*       STEPS  - number of steps                                      *
*                                                                     *
*     LOCAL:                                                          *
*       DAY    - 1 to 31                                              *
*       ELIP2  - square of the eccentricity of the earth              *
*       ELONG  - east longitude position of the ground station        *
*       GLAT   - geodetic latitude of the ground station              *
*       H      - altitude above the earth ellipsoid                   *
*       HOUR   - 0 to 23                                              *
*       JD     - Julian Date                                          *
*       KIND   - determines whether continuous visibility involves    *
*                a ground station and three satellites (0) or three   *
*                satellites (1)                                       *
*       MIN    - 0 to 59                                              *
*       MON    - 1 to 12                                              *
*       SEC    - 0 to 59                                              *
*       STATE  - variable that defines file number                    *
*       T      - time corresponding to a given step                   *
*       VAR    - variable that defines file number                    *
*       VIS    - value of the visibility function at a given step     *
*       YEAR   - 1900 to 2100                                         *
***********************************************************************
      SUBROUTINE GANDS(CHOICE,ELIP2,NUM,S2TU,SIZE,STEPS)

      REAL*8  DAY,ELIP2,ELONG,GLAT,H,HOUR,JD,MIN,MON,S2TU
      REAL*8  SEC,SIZE,T(0:2005),VIS(0:2005),YEAR
      INTEGER CHOICE,COUNT,IN,INTURN,KIND,NUM,OUT,STATE,STEPS,VAR

      OPEN(UNIT=31,FILE='GSPOS1.DAT',STATUS='NEW')
      OPEN(UNIT=32,FILE='GSPOS2.DAT',STATUS='NEW')
      OPEN(UNIT=33,FILE='GSPOS3.DAT',STATUS='NEW')
      OPEN(UNIT=34,FILE='GSPOS4.DAT',STATUS='NEW')
***********************************************************************
*   In order to accurately determine the position vectors of the      *
*   given ground station, it is necessary to know the exact time      *
*   (Universal Time) the simulation is to start.  The following       *
*   lines prompt the user to enter the year, month, day, hour, min-   *
*   ute, and second the simulation is to start.  The Julian Date      *
*   will be calculated from this information.                         *
***********************************************************************
      WRITE(*,*)'In order to determine position vectors of the earth'
      WRITE(*,*)'ground station(s), it is necessary to know the year,'
      WRITE(*,*)'month, day, and time when you wish the simulation to '
      WRITE(*,*)'begin.  The time of interest is Universal Time.'
      WRITE(*,*)'Please enter the following information:'
***********************************************************************
*                                YEAR                                 *
***********************************************************************
    5 WRITE(*,*)'  What is the year of interest, between 1900 and 2100?'
      WRITE(*,190)
      READ(*,*,ERR=5)YEAR
```

```
        GOTO 5
      ENDIF
*****************************************************************
*                              MONTH                            *
*****************************************************************
   10 WRITE(*,*)'  What is the month of interest?  Please enter the '
      WRITE(*,*)'  number of the month between 1 and 12.'
      WRITE(*,190)
      READ(*,*,ERR=10)MON
      IF (MON.LT.1.OR.MON.GT.12) THEN
         WRITE(*,*)'  The month you entered was not a valid response.'
         WRITE(*,*)'  Please re-enter the value.'
         GOTO 10
      ENDIF
*****************************************************************
*                               DAY                             *
*****************************************************************
   15 WRITE(*,*)'  What is the day of interest?  Please enter a value'
      WRITE(*,*)'  between 1 and 31.'
      WRITE(*,190)
      READ(*,*,ERR=15)DAY
      IF (DAY.LT.1.OR.DAY.GT.31) THEN
         WRITE(*,*)'  The day you entered was not valid.  Please'
         WRITE(*,*)'  re-enter the value'
         GOTO 15
      ELSE IF (MON.EQ.2.AND.DAY.GT.29) THEN
         WRITE(*,*)'February does not have more than 29 days. Please'
         WRITE(*,*)'reenter the month.'
         GOTO 15
      ELSE IF (DAY.EQ.31) THEN
         IF (MON.EQ.4.OR.MON.EQ.6.OR.MON.EQ.9.OR.MON.EQ.11) THEN
          WRITE(*,*)'  The month you entered does not have more than 30'
          WRITE(*,*)'  days.  Please re-enter the month.'
          GOTO 15
         ENDIF
      ENDIF
*****************************************************************
*                              HOUR                             *
*****************************************************************
      WRITE(*,*)'Next it is necessary to enter the time of interest.'
      WRITE(*,*)'This will be done by hour, minute, and second.  '
      WRITE(*,*)'Please respond at the prompt.'
      WRITE(*,*)
   20 WRITE(*,*)'  What is the hour you wish the simulation to begin?'
      WRITE(*,*)'  The value must be between 1 and 23.'
      WRITE(*,190)
      READ(*,*,ERR=20)HOUR
      IF (HOUR.LT.0.OR.HOUR.GT.23) THEN
         WRITE(*,*)'  The hour you entered was not valid.  Please '
         WRITE(*,*)'  re-enter the hour.'
         GOTO  20
      ENDIF
*****************************************************************
*                              MINUTE                           *
*****************************************************************
   25 WRITE(*,*)'  At what minute in the hour do you wish to begin.'
      WRITE(*,*)'  Please enter a number between 1 and 59.'
      WRITE(*,190)
      READ(*,*,ERR=25)MIN
      IF (MIN.LT.0.OR.MIN.GT.59) THEN
         WRITE(*,*)'  The minute you entered was not a valid response.'
         WRITE(*,*)'  Please re-enter the value.'
         GOTO 25
```

```
*********************************************************************
   30 WRITE(*,*)'  At what second do you wish to begin.  Please enter'
      WRITE(*,*)'  a number between 1 and 59.'
      WRITE(*,190)
      READ(*,*,ERR=30)SEC
      IF (SEC LT.0.OR.SEC.GT.59) THEN
         WRITE(*,*)'  The second you entered was not a valid response.'
         WRITE(*,*)'  Please re-enter the value.'
         GOTO 30
      ENDIF

      WRITE(25,150)MON,DAY,YEAR
      WRITE(25,160)HOUR,MIN,SEC
      WRITE(25,*)
*********************************************************************
*  The following line calls the subroutine JULDATE where the Julian *
*  Date is calculated.                                              *
*********************************************************************
      CALL JULDATE(DAY,HOUR,MIN,MON,SEC,YEAR,JD)
*********************************************************************
*  The following DO loop call for the user to enter the east        *
*  longitude and the geodetic latitude.  The ground station position *
*  vectors are then determined in subroutine GRNDST.                *
*********************************************************************
      DO 40 COUNT = 1,NUM
   33    WRITE(*,*)'Please enter the east longitude value for the '
         WRITE(*,200)COUNT
         WRITE(*,190)
         READ(*,*,ERR=33)ELONG
         IF (ELONG.LT.-360.0D0.OR.ELONG.GT.360.0D0) THEN
            WRITE(*,*)'The value of longitude entered was not valid.'
            WRITE(*,*)'Please re-enter the value.'
            GOTO 33
         ENDIF
         WRITE(25,220)COUNT
         WRITE(25,230)ELONG
   35    WRITE(*,*)'Please enter the geodetic latitude for the '
         WRITE(*,200)COUNT
         WRITE(*,*)'The value should be between -90 and 90 degrees.'
         WRITE(*,190)
         READ(*,*,ERR=35)GLAT

         IF (GLAT.LT.(-90.0D0).OR.GLAT.GT.(90.0D0)) THEN
            WRITE(*,*)'The geodetic latitude value you entered was not'
            WRITE(*,*)'acceptable.  Please re-enter the value.'
            GOTO 35
         ENDIF
         WRITE(25,240)GLAT

   38    WRITE(*,*)'Please enter the altitude of the ground station '
         WRITE(*,*)'above sea level (in KM).'
         WRITE(*,190)
         READ(*,*,ERR=38)H
         WRITE(25,250)H
         WRITE(25,*)
*********************************************************************
*  Next, the subroutine GRNDST is call where the position vectors of *
*  ground station are determined.                                   *
*********************************************************************
         CALL GRNDST(COUNT,ELIP2,ELONG,GLAT,H,JD,S2TU,STEPS)
   40 CONTINUE
      CLOSE(UNIT=31)
      CLOSE(UNIT=32)
```

```
*  The subroutine SATS is called in order to determine the rise set  *
*  times between the satellites entered in this portion of the       *
*  program.                                                          *
**********************************************************************
      CHOICE = CHOICE - 1
      CALL SATS(CHOICE,ELIP2,S2TU,SIZE,STEPS)
      CHOICE = CHOICE + 1
**********************************************************************
*  The following opens the necessary files, then records the vis-    *
*  ibility data to send to the subroutine BLEND.                     *
**********************************************************************
      DO 70 OUT = 1,NUM
         OPEN(UNIT=60,FILE='TRACKER.DAT',STATUS='UNKNOWN')
         OPEN(UNIT=41,FILE='STAT1.DAT',STATUS='NEW')
         OPEN(UNIT=42,FILE='STAT2.DAT',STATUS='NEW')
         OPEN(UNIT=43,FILE='STAT3.DAT',STATUS='NEW')
         OPEN(UNIT=44,FILE='STAT4.DAT',STATUS='NEW')

         VAR = 1

            DO 60 IN = 1,CHOICE
               IF (OUT.EQ.1.AND.IN.EQ.1) THEN
                 OPEN(UNIT=31,FILE='GSPOS1.DAT',STATUS='OLD')
                 OPEN(UNIT=1,FILE='POS1.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.1.AND.IN.EQ.2) THEN
                 OPEN(UNIT=31,FILE='GSPOS1.DAT',STATUS='OLD')
                 OPEN(UNIT=2,FILE='POS2.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.1.AND.IN.EQ.3) THEN
                 OPEN(UNIT=31,FILE='GSPOS1.DAT',STATUS='OLD')
                 OPEN(UNIT=3,FILE='POS3.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.1.AND.IN.EQ.4) THEN
                 OPEN(UNIT=31,FILE='GSPOS1.DAT',STATUS='OLD')
                 OPEN(UNIT=4,FILE='POS4.DAT',STATUS='OLD')

               ELSE IF (OUT.EQ.2.AND.IN.EQ.1) THEN
                 OPEN(UNIT=32,FILE='GSPOS2.DAT',STATUS='OLD')
                 OPEN(UNIT=1,FILE='POS1.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.2.AND.IN.EQ.2) THEN
                 OPEN(UNIT=32,FILE='GSPOS2.DAT',STATUS='OLD')
                 OPEN(UNIT=2,FILE='POS2.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.2.AND.IN.EQ.3) THEN
                 OPEN(UNIT=32,FILE='GSPOS2.DAT',STATUS='OLD')
                 OPEN(UNIT=3,FILE='POS3.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.2.AND.IN.EQ.4) THEN
                 OPEN(UNIT=32,FILE='GSPOS2.DAT',STATUS='OLD')
                 OPEN(UNIT=4,FILE='POS4.DAT',STATUS='OLD')

               ELSE IF (OUT.EQ.3.AND.IN.EQ.1) THEN
                 OPEN(UNIT=33,FILE='GSPOS3.DAT',STATUS='OLD')
                 OPEN(UNIT=1,FILE='POS1.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.3.AND.IN.EQ.2) THEN
                 OPEN(UNIT=33,FILE='GSPOS3.DAT',STATUS='OLD')
                 OPEN(UNIT=2,FILE='POS2.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.3.AND.IN.EQ.3) THEN
                 OPEN(UNIT=33,FILE='GSPOS3.DAT',STATUS='OLD')
                 OPEN(UNIT=3,FILE='POS3.DAT',STATUS='OLD')
               ELSE IF (OUT.EQ.3.AND.IN.EQ.4) THEN
                 OPEN(UNIT=33,FILE='GSPOS3.DAT',STATUS='OLD')
                 OPEN(UNIT=4,FILE='POS4.DAT',STATUS='OLD')

               ELSE IF (OUT.EQ.4.AND.IN.EQ.1) THEN
                 OPEN(UNIT=34,FILE='GSPOS4.DAT',STATUS='OLD')
                 OPEN(UNIT=1,FILE='POS1.DAT',STATUS='OLD')
```

```
                  ...(UNIT=34,FILE='GSPOS3.DAT',STATUS='OLD')
                ELSE IF (OUT.EQ.4.AND.IN.EQ.3) THEN
                  OPEN(UNIT=34,FILE='GSPOS4.DAT',STATUS='OLD')
                  OPEN(UNIT=3,FILE='POS3.DAT',STATUS='OLD')
                ELSE IF (OUT.EQ.4.AND.IN.EQ.4) THEN
                  OPEN(UNIT=34,FILE='GSPOS4.DAT',STATUS='OLD')
                  OPEN(UNIT=4,FILE='POS4.DAT',STATUS='OLD')
                ENDIF

              CALL SATGRN(IN,OUT,SIZE,STEPS)
                 CLOSE(UNIT=OUT+30)
                 CLOSE(UNIT=IN)

                 OPEN(UNIT=40,FILE='GSVIS.DAT',STATUS='OLD')
                    DO 50 INTURN = 1,STEPS+1
                       READ(40,*)T(INTURN),VIS(INTURN)
                       IF (IN.EQ.1) THEN
                          OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='UNKNOWN')
                          WRITE(10,*)T(INTURN),VIS(INTURN)
                          CLOSE(UNIT=10)
                       ELSE IF (IN.EQ.2) THEN
                          OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='UNKNOWN')
                          WRITE(11,*)T(INTURN),VIS(INTURN)
                          CLOSE(UNIT=11)
                       ELSE IF (IN.EQ.3) THEN
                          OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='UNKNOWN')
                          WRITE(12,*)T(INTURN),VIS(INTURN)
                          CLOSE(UNIT=12)
                       ELSE IF (IN.EQ.4) THEN
                          OPEN(UNIT=13,FILE='VIS4.DAT',STATUS='UNKNOWN')
                          WRITE(13,*)T(INTURN),VIS(INTURN)
                          CLOSE(UNIT=13)
                       ENDIF
 50                 CONTINUE

    WRITE(25,*)
    WRITE(25,260)OUT,IN
    CLOSE(UNIT = 40)

    STATE = VAR+40
    CALL BLEND(STATE,STEPS,T,VIS)
    CLOSE(UNIT=STATE)
    VAR=VAR+1

 60 CONTINUE
    IF (CHOICE.EQ.2) THEN
       WRITE(25,*)
       WRITE(25,265)OUT
       WRITE(25,285)
       STATE = 41
       CALL GSSCVC2(STATE)
    ELSE IF (CHOICE.EQ.3) THEN
       WRITE(25,*)
       WRITE(25,270)OUT
       WRITE(25,285)
       KIND = 0
       STATE = 41
       CALL CVC3(KIND,STATE)
    ELSE IF (CHOICE.EQ.4) THEN
       WRITE(25,*)
       WRITE(25,280)OUT
       WRITE(25,285)
       STATE = 41
       CALL GSSCVC4(STATE)
```

```
 70  CONTINUE

     RETURN

 150 FORMAT('DATE FOR BEGINNING THE SIMULATION: ',I2,'/',I2,'/',I4)
 160 FORMAT('TIME FOR BEGINNING THE SIMULATION: ',I2,':',I2,'.',I2)
 190 FORMAT(2X,'====> ')
 200 FORMAT(' location of ground station #',I1,'.')
 220 FORMAT('THE LOCATION OF GROUND STATION #',I1)
 230 FORMAT('EAST LONGITUDE: ',F12.6)
 240 FORMAT('GEODETIC LATITUDE: ',F12.6)
 250 FORMAT('ALTITUDE ABOVE THE EARTH ELLIPSOID: ',F12.6)
 260 FORMAT('RISE AND SET TIMES BETWEEN GROUND STATION #',I1,' AND
    + SATELLITE #',I1,':')
 265 FORMAT('COMMUNICATIONS STATUS BETWEEN GROUND STATION #',I1,' AND
    + THE TWO GIVEN SATELLITES:')
 270 FORMAT('COMMUNICATIONS STATUS BETWEEN GROUND STATION #',I1,' AND
    + THE THREE GIVEN SATELLITES:')
 280 FORMAT('COMMUNICATIONS STATUS BETWEEN GROUND STATION #',I1,' AND
    + THE FOUR GIVEN SATELLITES:')
 285 FORMAT('(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS
    + COMMUNICATIONS.)')
     END
*
```

```
*                                                                      *
*  PURPOSE:   The purpose of this subroutine is to determine the       *
*             visibility function between a given satellite and a      *
*             given ground station.                                    *
*                                                                      *
*   VARIABLES:                                                         *
*     INPUT:                                                           *
*       IN      - do loop counter representing the number of sat's     *
*       OUT     - do loop counter representing the number of ground    *
*                 stations                                             *
*       SIZE    - step size                                            *
*       STEPS   - total number of steps                                *
*                                                                      *
*     LOCAL:                                                           *
*       COUNT   - do loop counter                                      *
*       PHI     - angle between the position vector to the satellite   *
*                 and the position vector to the ground station        *
*       R1      - position vector to the ground station                *
*       R2      - position vector to the satellite                     *
*       VIS     - value of the visibility function between satellite   *
*                 and ground station                                   *
*                                                                      *
*   REFERENCES:  Lawson, 32                                            *
*                Alfano, Negron, and Moore, 2                          *
************************************************************************
      SUBROUTINE SATGRN(IN,OUT,SIZE,STEPS)

      REAL*8  PHI,R1(4),R2(4),SIZE,VIS
      INTEGER COUNT,IN,OUT,STEPS
************************************************************************
*  GSVIS.DAT contains visibility data between the given satellite and  *
*  ground station.  This file will be overwritten each time SATGRN is  *
*  called.                                                             *
************************************************************************
      OPEN(UNIT=40,FILE='GSVIS.DAT',STATUS='UNKNOWN')
      DO 20 COUNT = 0,STEPS

         READ(OUT+30,*)R1(1),R1(2),R1(3),R1(4)
         READ(IN,*)R2(1),R2(2),R2(3),R2(4)
************************************************************************
*  The next lines define the visibility function between the satellite *
*  and the ground station.                                             *
*  Reference:  Lt Col Salvatore Alfano                                 *
************************************************************************
      PHI = ((R1(1)*R2(1))+(R1(2)*R2(2))+(R1(3)*R2(3)))/(R1(4)*R2(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = DACOS((R1(4))/R2(4)) - DACOS(PHI)

      WRITE(40,110)COUNT*SIZE,VIS

   20 CONTINUE

      CLOSE(UNIT=40)

      RETURN
```

```
  110 FORMAT(I10,5X,F12.5)
      END
*
```

```
*                      SUBROUTINE JULDATE                                *
*                                                                        *
*   PURPOSE:  The purpose of this subroutine is to convert convention-*
*             al time to Julian Date.                                    *
*                                                                        *
*   VARIABLES:                                                           *
*     INPUT:                                                             *
*       DAY      - 1 to 31                                               *
*       HR       - 0 to 23                                               *
*       MIN      - 0 to 59                                               *
*       MON      - 1 to 12                                               *
*       SEC      - 0 to 59                                               *
*       YEAR     - 1900 to 2100                                          *
*     OUTPUT:                                                            *
*       JD       - Julian Date                                           *
*                                                                        *
*  Reference:  Valado, 1                                                 *
**************************************************************************
      SUBROUTINE JULDATE(DAY,HOUR,MIN,MON,SEC,YEAR,JD)

      REAL*8 DAY,HOUR,MIN,MON,SEC,YEAR,JD

      JD = 367.0D0*(YEAR)-DINT((7.0D0*(YEAR+DINT((MON+9.0D0)/12.0D0)))
     +     /4.0D0)+DINT((275.0D0*MON)/9.0D0)+DAY+1721013.5D0+
     +     ((((SEC/60.0D0)+MIN)/60.0D0)+HOUR)/24.0D0

      RETURN
      END
*
```

```
*                      SUBROUTINE GRNDST                              *
*                                                                     *
*  PURPOSE:  The purpose of this subroutine is to determine the       *
*            geocentric position of a ground station given Julian     *
*            Date, east longitude, and geodetic latitude.             *
*                                                                     *
*  VARIABLES:                                                         *
*    INPUT:                                                           *
*      ELIP2    - square of the eccentricity of the earth            *
*      ELONG    - east longitude of the station of interest          *
*      GLAT     - geodetic longitude of the station of interest      *
*      H        - altitude of the station above the earth ellipsoid  *
*      JD       - Julian Date                                        *
*      S2TU     - converts SEC to TU                                 *
*      STEPS    - number of steps                                    *
*                                                                     *
*    LOCAL VARIABLES:                                                 *
*      COSLAT   - cosine of the geodetic latitude                    *
*      DEGRAD   - conversion from degrees to radians                 *
*      DENOM    - denominator of the equation to determine G1 and G2 *
*      DT       - change in time                                     *
*      GLAT     - geodetic latitude of the ground station            *
*      GSR(1-4) - position vectors of the ground station             *
*      KM2DU    - conversion from km to DU                           *
*      REP      - counter for do loop                                *
*      SINLAT   - sine of the geodetic latitude                      *
*      TGO      - Greenwich Sidereal Time at 0 hr Universal Time     *
*      THETA    - observers local sidereal time                      *
*      THETDOT  - time rate of change of the local sidereal time     *
*                 based on the rotation of the earth (rad/TU)       *
*      THETG    - sidereal time of the Greenwich Meridian            *
*      TU       - time measured in centuries                         *
*      TWOPI    - two times pi                                       *
*      X        - variable for the determination of station position *
*                 vector                                            *
*                                                                     *
*     Reference:  Valado, 2-4                                         *
*                 Bates, Mueller, and White, 98-103                   *
*                 Escobal, 20-21                                      *
*                 Alfano, Negron, and Moore, 6                        *
***********************************************************************
      SUBROUTINE GRNDST(COUNT,ELIP2,ELONG,GLAT,H,JD,S2TU,STEPS)

      REAL*8  COSLAT,DEGRAD,DENOM,DT,ELIP2,ELONG,GLAT
      REAL*8  GSR(4),H,JD,KM2DU,S2TU,SINLAT,TGO
      REAL*8  THETA,THETDOT,THETG,TU,TWOPI,X
      INTEGER COUNT,REP,STEPS
***********************************************************************
*                           CONSTANTS                                 *
***********************************************************************
      TWOPI    = 2.0D0*DACOS(-1.0D0)
      DEGRAD   = TWOPI/360.0D0
      KM2DU    = (1.0D0/6378.137D0)

      ELONG = ELONG*DEGRAD
      GLAT  = GLAT*DEGRAD
      H     = H*KM2DU

      THETDOT = .05883359068878 6D0
***********************************************************************
*  The following lines calculate the Greenwich Sidereal Time and      *
*  to be used in the determination of the Local Sidereal Time.        *
***********************************************************************
```

```
      ------   ------,------)

      TU      = (DINT(JD) + .5D0 - 2451545.0D0)/36525.0D0
      TGO     = 1.753368559D0+628.3319705D0*TU+
     +          .0C0006770708127D0*(TU**2.0D0)+(6.30038809866574)*
     +          DBLE(JD-DINT(JD)-.5D0)

      TGO     = DMOD(TGO,TWOPI)
      IF (TGO.LT.(0.0D0)) THEN
         TGO = TWOPI+TGO
      ENDIF

      DENOM   = DSQRT(1.0D0-(ELIP2*(SINLAT**2.0D0)))

      X       = ((1.0D0/DENOM)+H)*COSLAT
      GSR(3) = ((((1.0D0-ELIP2)/DENOM)+H)*SINLAT*(1.0D0/
     +          DSQRT(1.0D0-ELIP2))
      GSR(4) = DSQRT((X**2.0D0)+(GSR(3)**2.0D0))

      TGO = 0.0D0
*************************************************************************
*   The following lines calculate the x and z variables for the         *
*   position of the ground station.  These variables are then used      *
*   to calculate the position vector in the IJK or geocentric coor-     *
*   dinate system.                                                      *
*************************************************************************
      DO 50 REP = 0,STEPS
         DT     = REP*S2TU
         THETG = TGO + THETDOT*DT
         THETA = THETG + ELONG

         GSR(1) = X*DCOS(THETA)
         GSR(2) = X*DSIN(THETA)

      WRITE(COUNT+30,100)GSR(1),GSR(2),GSR(3),GSR(4)

   50 CONTINUE
      RETURN

  100 FORMAT(F12.5,5X,F12.5,5X,F12.5,5X,F12.5)

      END
```

```
*                      SUBROUTINE SATS                                  *
*                                                                       *
*   PURPOSE:                                                            *
*                                                                       *
*   VARIABLES:                                                          *
*    ORBITAL ELEMENTS:                                                  *
*     ARGP     - argument of periapsis for @ orbit          (DEG)      *
*     AXIS     - semi-major axis for @ orbit                (KM)       *
*     ECC      - eccentricity for @ orbit                              *
*     INC      - inclination for @ orbit                    (DEG)      *
*     MA       - mean anomoly for @ orbit                   (DEG)      *
*     NODE     - longitude of the ascending node for @ orbit (DEG)     *
*                                                                       *
*    OTHER VARIABLES:                                                   *
*     AKM      - value of the semi-major axis in KM                    *
*     CHOICE   - reflects the users choice for operation               *
*     COUNT    - DO loop counter                                       *
*     D2RAD    - converts DEG to RAD                                   *
*     DU2KM    - converts DUs to KM                                    *
*     ELIP2    - square of the eccentricity of the earth               *
*     KIND     - differentiates between a ground station and three     *
*                satellites (0) and three satellites (1)                *
*     N        - mean motion of the satellites              (DU/TU)    *
*     S2TU     - converts SEC to TU                                    *
*     SIZE     - step size (SEC)                                       *
*     STATE    - file number                                           *
*     STEPS    - number of steps                                       *
*     T        - chronological time over time span                     *
*     TWOPI    - twice the value of pi                                 *
*     VIS      - value of the visibility function                      *
*                                                                       *
*************************************************************************
      SUBROUTINE SATS(CHOICE,ELIP2,S2TU,SIZE,STEPS)

      REAL*8  AKM,ARGP,AXIS,D2RAD,DU2KM,ECC,ELIP2,INC,MA,NODE
      REAL*8  S2TU,SIZE,T(0:500),TWOPI,VIS(0:500),N
      INTEGER CHOICE,COUNT,KIND,STATE,STEPS

      OPEN(UNIT=1,FILE='POS1.DAT',STATUS='NEW')
      OPEN(UNIT=2,FILE='POS2.DAT',STATUS='NEW')
      OPEN(UNIT=3,FILE='POS3.DAT',STATUS='NEW')
      OPEN(UNIT=4,FILE='POS4.DAT',STATUS='NEW')
      OPEN(UNIT=60,FILE='TRACKER.DAT',STATUS='NEW')
*************************************************************************
*                          CONSTANTS                                    *
*************************************************************************
      TWOPI = 2.0D0*DACOS(-1.0D0)
      D2RAD = (TWOPI/360.0D0)
      DU2KM = 6378.137D0
*************************************************************************
*   The following prompts the user to enter the values of the           *
*   orbital elements for the satellites of interest.                    *
*************************************************************************
      DO 20 COUNT = 1,CHOICE+1
         ECC  = 0.0D0
         AXIS = 0.0D0
         INC  = 0.0D0
         MA   = 0.0D0
         NODE = 0.0D0
         ARGP = 0.0D0
         N    = 0.0D0

         WRITE(25,510)COUNT
```

```
      WRITE(25,520)ECC
   12 WRITE(*,*)'Mean Motion (rev/day) ==> '
      READ(*,*,ERR=12)N
        N = N*.05867301522d0
        AXIS = (1.0D0/(N**2.0D0))**(.333333D0)
        AKM  = AXIS*DU2KM
        WRITE(25,530)AKM
   13 WRITE(*,*)'Inclination ==> '
      READ(*,*,ERR=13)INC
      WRITE(25,540)INC
   14 WRITE(*,*)'Mean Anomoly (DEG) ==> '
      READ(*,*,ERR=14)MA
      WRITE(25,550)MA
   15 WRITE(*,*)'Longitude of the Ascending Node (DEG) ==> '
      READ(*,*,ERR=15)NODE
      WRITE(25,560)NODE
   16 WRITE(*,*)'Argument of Periapsis (DEG) ==> '
      READ(*,*,ERR=16)ARGP
      WRITE(25,570)ARGP
      WRITE(25,*)
      WRITE(*,*)
      WRITE(*,*)'Please stand-by.  Calculations are in progress.'
      WRITE(*,*)
*************************************************************************
*  The following converts the values entered from KM to DU, or from *
*  DEG to RAD.                                                          *
*************************************************************************
      INC  = INC*D2RAD
      MA   = MA*D2RAD
      NODE = NODE*D2RAD
      ARGP = ARGP*D2RAD

      CALL POS(COUNT,ELIP2,S2TU,STEPS,AXIS,ECC,INC,N,NODE,ARGP,MA)
      CLOSE(UNIT = COUNT)

   20 CONTINUE

      IF (CHOICE.EQ.0) THEN
         GOTO 400
      ENDIF
*************************************************************************
*  In the following if loop, the computer calls the subroutine      *
*  necessary to check all options of visibility depending on the    *
*  number of satellites in consideration.                           *
*************************************************************************
*            2 SATELLITES                                           *
*************************************************************************
      WRITE(*,*)'The computer is in the process of determining ise'
      WRITE(*,*)'and set times.  Please stand by.'
      IF (CHOICE.EQ.1) THEN
         CALL TWOVIS(STEPS,SIZE)
         OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='OLD')
         DO 30 COUNT = 1,STEPS+1
            READ(10,*)T(COUNT),VIS(COUNT)
   30    CONTINUE
         CLOSE(UNIT=10)
         WRITE(25,*)
         WRITE(25,600)

         STATE = 41
         OPEN(UNIT=41,FILE='STAT1.DAT',STATUS='NEW')
         CALL BLEND(STATE,STEPS,T,VIS)
```

```
************************************************************************
      ELSE IF (CHOICE.EQ.2) THEN
         CALL THRVIS(STEPS,SIZE)
         OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='OLD')
         DO 40 COUNT = 1,STEPS+1
            READ(10,*)T(COUNT),VIS(COUNT)
   40    CONTINUE
         CLOSE(UNIT=10)
         WRITE(25,*)
         WRITE(25,600)

         STATE = 41
         OPEN(UNIT=41,FILE='STAT1.DAT',STATUS='NEW')
         CALL BLEND(STATE,STEPS,T,VIS)
         CLOSE(UNIT=41)

         OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='OLD')
         DO 50 COUNT = 1,STEPS+1
            READ(11,*)T(COUNT),VIS(COUNT)
   50    CONTINUE
         CLOSE(UNIT=11)
         WRITE(25,*)
         WRITE(25,630)

         STATE=42
         OPEN(UNIT=42,FILE='STAT2.DAT',STATUS='NEW')
         CALL BLEND(STATE,STEPS,T,VIS)
         CLOSE(UNIT=42)

         OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='OLD')
         DO 60 COUNT = 1,STEPS+1
            READ(12,*)T(COUNT),VIS(COUNT)
   60    CONTINUE
         CLOSE(UNIT=12)
         WRITE(25,*)
         WRITE(25,620)

         STATE=43
         OPEN(UNIT=43,FILE='STAT3.DAT',STATUS='NEW')
         CALL BLEND(STATE,STEPS,T,VIS)
         CLOSE(UNIT=43)
         CLOSE(UNIT=60)

         KIND = 1
         STATE=41
         WRITE(25,*)
         WRITE(25,660)
         WRITE(25,665)
         CALL CVC3(KIND,STATE)
************************************************************************
*            4 SATELLITES                                              *
************************************************************************
      ELSE IF (CHOICE.EQ.3) THEN
         CALL FOURVIS(STEPS,SIZE)
         OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='OLD')
         DO 70 COUNT = 1,STEPS+1
            READ(10,*)T(COUNT),VIS(COUNT)
   70    CONTINUE
         CLOSE(UNIT=10)
         WRITE(25,*)
         WRITE(25,600)

         STATE=41
```

```
      OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='OLD')
      DO 80 COUNT = 1,STEPS+1
         READ(11,*)T(COUNT),VIS(COUNT)
 80   CONTINUE
      CLOSE(UNIT=11)
      WRITE(25,*)
      WRITE(25,610)

      STATE=42
      OPEN(UNIT=42,FILE='STAT2.DAT',STATUS='NEW')
      CALL BLEND(STATE,STEPS,T,VIS)
      CLOSE(UNIT=42)

      OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='OLD')
      DO 90 COUNT = 1,STEPS+1
         READ(12,*)T(COUNT),VIS(COUNT)
 90   CONTINUE
      CLOSE(UNIT=12)
      WRITE(25,*)
      WRITE(25,620)

      STATE=43
      OPEN(UNIT=43,FILE='STAT3.DAT',STATUS='NEW')
      CALL BLEND(STATE,STEPS,T,VIS)
      CLOSE(UNIT=43)

      OPEN(UNIT=13,FILE='VIS4.DAT',STATUS='OLD')
      DO 100 COUNT = 1,STEPS+1
         READ(13,*)T(COUNT),VIS(COUNT)
100   CONTINUE
      CLOSE(UNIT=13)
      WRITE(25,*)
      WRITE(25,630)

      STATE=44
      OPEN(UNIT=44,FILE='STAT4.DAT',STATUS='NEW')
      CALL BLEND(STATE,STEPS,T,VIS)
      CLOSE(UNIT=44)

      OPEN(UNIT=14,FILE='VIS5.DAT',STATUS='OLD')
      DO 110 COUNT = 1,STEPS+1
         READ(14,*)T(COUNT),VIS(COUNT)
110   CONTINUE
      CLOSE(UNIT=14)
      WRITE(25,*)
      WRITE(25,640)

      STATE=45
      OPEN(UNIT=45,FILE='STAT5.DAT',STATUS='NEW')
      CALL BLEND(STATE,STEPS,T,VIS)
      CLOSE(UNIT=45)

      OPEN(UNIT=15,FILE='VIS6.DAT',STATUS='OLD')
      DO 120 COUNT = 1,STEPS+1
         READ(15,*)T(COUNT),VIS(COUNT)
120   CONTINUE
      CLOSE(UNIT=15)
      WRITE(25,*)
      WRITE(25,650)

      STATE=46
      OPEN(UNIT=46,FILE='STAT6.DAT',STATUS='NEW')
```

```
          STATE=41
          WRITE(25,*)
          WRITE(25,670)
          WRITE(25,665)
          CALL CVC4(STATE)

       ENDIF

       CLOSE(UNIT=60,STATUS='DELETE')

  400 CONTINUE

       RETURN

  500 FORMAT(' elements of satellite #',I1,':')
  510 FORMAT('INITIAL ORBITAL ELEMENTS OF SATELLITE #',I1,':')
  520 FORMAT(3X,'Eccentricity    : ',F12.10)
  530 FORMAT(3X,'Semi-major Axis : ',F15.8,' KM')
  540 FORMAT(3X,'Inclination     : ',F15.8,' DEG')
  550 FORMAT(3X,'Mean Anomoly    : ',F15.8,' DEG')
  560 FORMAT(3X,'Longitude of the Ascending Node : ',F15.8,' DEG')
  570 FORMAT(3X,'Argument of Periapsis           : ',F15.8,' DEG')
  600 FORMAT('Rise/Set Times between Satellite #1 and Satellite #2:')
  610 FORMAT('Rise/Set Times between Satellite #1 and Satellite #3:')
  620 FORMAT('Rise/Set Times between Satellite #1 and Satellite #4:')
  630 FORMAT('Rise/Set Times between Satellite #2 and Satellite #3:')
  640 FORMAT('Rise/Set Times between Satellite #2 and Satellite #4:')
  650 FORMAT('Rise/Set Times between Satellite #3 and Satellite #4:')
  660 FORMAT('COMMUNICATIONS STATUS BETWEEN SATELLITE #1, #2, AND #3:')
  665 FORMAT('(NOTE: NO ENTRIES OR MESSAGE BELOW INDICATES CONTINUOUS
     + COMMUNICATIONS.)')
  670 FORMAT('COMMUNICATIONS STATUS BETWEEN SATELLITE #1, #2, #3, AND
     + #4:')
       END
*
```

```
*                    SUBROUTINE POS                                    *
*                                                                      *
*  PURPOSE:  The purpose of this subroutine is to determine the        *
*            position of a satellite given the classical orbital       *
*            elements.                                                 *
*  VARIABLES:                                                          *
*   INPUT:                                                             *
*     ARGP      - argument of periapsis for @ orbit          (RAD)     *
*     AXIS      - semi-major axis for @ orbit                (DU)      *
*     COUNT     - DO loop counter; indicates the satellite number      *
*     ECC       - eccentricity for @ orbit                             *
*     ELIP2     - square of the eccentricity of the earth              *
*     INC       - inclination for @ orbit                    (RAD)     *
*     MA        - mean anomoly for @ orbit                   (RAD)     *
*     NODE      - longitude of the ascending node for @ orbit (RAD)    *
*     S2TU      - time step                                  (TU)      *
*     STEPS     - number of steps in the requested interval            *
*                                                                      *
*   LOCAL VARIABLES:                                                   *
*     COSARGP   - cosine of the argument of periapsis                  *
*     COSFINALE - final value of the cosine of the eccentric anomoly   *
*     COSINC    - cosine of the inclination                            *
*     COSNODE   - cosine of the longitude of the ascending node        *
*     COSNU     - cosine of the true anomoly                           *
*     DENOM     - variable for the denominator of a given quotient     *
*     DIF       - difference between two value of the eccentric        *
*                 anomoly during Newton-Rhapson Itteration             *
*     ECOSFE    - eccentricity multiplied by the cosine of the         *
*                 finale value of the eccentric anomoly                *
*     EN        - first value of the eccentric anomoly for use in      *
*                 the Newton-Rhapson Itteration                        *
*     ENPLUSONE - second value of the eccentric anomoly as             *
*                 calculated in the Newton-Rhapson Itteration          *
*     FINALE    - final value of the eccentric anomoly reached by      *
*                 convergence of the Newton-Rhapson Itteration         *
*     J2        -                                                      *
*     M         - value of the mean anomoly at each time step          *
*     MN        - value of the mean anomoly calculated using a         *
*                 given value for the eccentric anomoly (used in the   *
*                 Newton-Rhapson Itteration)                           *
*     MULT      - matrix used to rotate the position vectors from      *
*                 the perifocal reference frame to the geocentric      *
*                 reference frame                                      *
*     N         - mean motion of the satellite                         *
*     NANOM     - anomolistic mean motion                              *
*     NEWARGP   - propogated argument of periapsis                     *
*     NEWNODE   - propogated longitude of the ascending node           *
*     P         - calculated value of the semi-latus rectum for the    *
*                 orbit                                                *
*     R         - calculated position vectors of the satellite         *
*     REP       - DO loop counter                                      *
*     RPQW      - position vectors of the satellite in the perifocal   *
*                 frame                                                *
*     SINARGP   - sine of the argument of periapsis                    *
*     SINFINE   - sine of the final value of the eccentric anomoly     *
*     SININC    - sine of the inclination of the orbit                 *
*     SINNODE   - sine of the longitude of the ascending node          *
*     SINNU     - sine of the true anomoly                             *
*     TWOPI     - constant; two multiplied by pi                       *
*                                                                      *
*     REFERENCES:   Bates, Mueller, and White, 187, 219-222            *
************************************************************************
      SUBROUTINE POS(COUNT,ELIP2,S2TU,STEPS,AXIS,ECC,INC,N,NODE,ARGP,MA)
```

```
      ...,SINARGP,SINFINE,SININC,SINNODE,SINNU,TWOPI,N,NANOM,NEWARGP,NEWNODE
      REAL*8  NODEDOT,NODE,NU,P,R(4),RPQW(4),S2TU,SINARGP
      REAL*8  SINFINE,SININC,SINNODE,SINNU,TWOPI
      INTEGER COUNT,REP,STEPS
*****************************************************************
*  The following computes values of variables which will be used *
*  multiple times within the program.  This is done to decrease the *
*  amount of calculation necessary within the subroutine.        *
*****************************************************************
      COSINC  = DCOS(INC)
      SININC  = DSIN(INC)

      J2      = .00108262D0
      TWOPI   = 2.0D0*DACOS(-1.0D0)
      P       = AXIS*(1.0D0 - (ECC**2.0D0))
      N       = N*S2TU
*****************************************************************
*  The following calculates the values necessary to propogate the *
*  satellite forward in its orbit.                               *
*****************************************************************
      NANOM   = N*(1.0D0+((1.5D0*J2*(DSQRT(1.0D0-(ECC**2.0D0)))/
     +          (P**2.0D0))*(1.0D0-(1.5D0*(SININC**2.0D0)))))
      NODEDOT = -(1.5D0*(J2/P**2.0D0)*COSINC)*NANOM
      ARGPDOT = (1.5D0*(J2/P**2.0D0)*(2.0D0-(2.5D0*
     +          (SININC**2.0D0))))*NANOM

      DO 50 REP = 0,STEPS
         NEWNODE = DMOD((NODE + (NODEDOT)*REP),TWOPI)
         NEWARGP = DMOD((ARGP + (ARGPDOT)*REP),TWOPI)
         COSNODE = DCOS(NEWNODE)
         SINNODE = DSIN(NEWNODE)
         COSARGP = DCOS(NEWARGP)
         SINARGP = DSIN(NEWARGP)
*****************************************************************
*  The following 3x3 matrix is used to transform the position vector*
*  from the PQW (perifocal) frame to the IJK (geocentric) frame.  *
*****************************************************************
         MULT(1,1) =  COSNODE*COSARGP - SINNODE*SINARGP*COSINC
         MULT(1,2) = -COSNODE*SINARGP - SINNODE*COSARGP*COSINC
         MULT(1,3) =  SINNODE*SININC
         MULT(2,1) =  SINNODE*COSARGP + COSNODE*SINARGP*COSINC
         MULT(2,2) = -SINNODE*SINARGP + COSNODE*COSARGP*COSINC
         MULT(2,3) = -COSNODE*SININC
         MULT(3,1) =  SINARGP*SININC
         MULT(3,2) =  COSARGP*SININC
         MULT(3,3) =  COSINC
*****************************************************************
*  In the next loop, the Newton-Rhapson iteration is carried out in *
*  order to determine the value of the eccentric anomoly at every *
*  time step in the orbit of the satellite.                      *
*****************************************************************
         M = DMOD((MA + (NANOM*REP)),TWOPI)
         EN = M
   10    MN = EN - ECC*(DSIN(EN))
         ENPLUSONE = (EN + ((M - MN)/(1.0D0 - (ECC*(DCOS(EN))))))
         DIF = DABS(EN - ENPLUSONE)

      IF (DIF.GT.(.000001D0)) THEN
         EN = ENPLUSONE
         GOTO 10
      ELSE
         FINALE = ENPLUSONE
      ENDIF
```

```
      ECOSFE  = ECC*COSFINE
      DENOM   = AXIS*(1.0D0 - (ECC*COSFINE))

      COSNU = (ECC - COSFINE)/(ECOSFE - 1.0D0)
      SINNU = ((AXIS*(DSQRT(1.0D0 - ECC**2.0D0)))*SINFINE)/DENOM
      NU    = DATAN2(SINNU,COSNU)

      COSNU = DCOS(NU)
      SINNU = DSIN(NU)
*************************************************************************
*  In the next three lines, the position vector in the perifocal        *
*  coordinate system is calculated.                                     *
*************************************************************************
      RPQW(1) = (P*COSNU)/(1.0D0 + (ECC*COSNU))
      RPQW(2) = (P*SINNU)/(1.0D0 + (ECC*COSNU))
      RPQW(3) = 0.0D0
*************************************************************************
*  The next lines transform the RPQW vector to the geocentric           *
*  coordinate frame.                                                    *
*************************************************************************
      R(1) = RPQW(1)*MULT(1,1) + RPQW(2)*MULT(1,2)
      R(2) = RPQW(1)*MULT(2,1) + RPQW(2)*MULT(2,2)
      R(3) = (RPQW(1)*MULT(3,1) + RPQW(2)*MULT(3,2))*(1.0D0/DSQRT(1.0D0
     +       - ELIP2))
      R(4) = DSQRT((R(1)**2.0D0) + (R(2)**2.0D0) + (R(3)**2.0D0))

      WRITE(COUNT,100)R(1),R(2),R(3),R(4)

   50 CONTINUE
      RETURN

  100 FORMAT(F12.5,5X,F12.5,5X,F12.5,5X,F12.5)

      END
*
```

```
*                    SUBROUTINE TWOVIS                                  *
*                                                                       *
*  PURPOSE:  This subroutine examines the visibility opportunities      *
*            between two satellites.                                    *
*                                                                       *
*  VARIABLES:                                                           *
*   INPUT:                                                              *
*     STEPS     - number of steps in the requested interval             *
*     SIZE      - step size (SEC)                                       *
*                                                                       *
*  LOCAL VARIABLES:                                                     *
*     COUNT     - DO loop counter                                       *
*     FILNUM    - file number                                           *
*     PHI       - angle between position vectors R1 and R2              *
*     R1        - position vector to satellite #1                       *
*     R2        - position vector to satellite #2                       *
*     VIS       - visibility function between satellites #1 and #2      *
*                                                                       *
*  REFERENCES:  Larson, 32                                              *
*               Alfano, Negron, and Moore, 2                            *
*               (These references apply to THRVIS and FOURVIS also)     *
************************************************************************
      SUBROUTINE TWOVIS(STEPS,SIZE)

      INTEGER COUNT,STEPS
      REAL*8  PHI,R1(4),R2(4),SIZE,VIS

      OPEN(UNIT=1,FILE='POS1.DAT',STATUS='OLD')
      OPEN(UNIT=2,FILE='POS2.DAT',STATUS='OLD')
************************************************************************
* VIS.DAT CONTAINS VISIBILITY DATA BETWEEN SATELLITES ONE AND TWO      *
************************************************************************
      OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='NEW')

      DO 20 COUNT = 0,STEPS
         READ(1,*)R1(1),R1(2),R1(3),R1(4)
         READ(2,*)R2(1),R2(2),R2(3),R2(4)
************************************************************************
*  The next lines define the visibility function.  According to this   *
*  idea, consider a plane tangent to the earth as the line below which *
*  satellite to satellite visibility is not possible.  The visibility  *
*  function calculated here compares angles to determine whether the   *
*  satellites are above or below the tangent plane.  In this instance  *
*  only two satellites are involved.                                   *
************************************************************************
*                  Satellites #1 and #2                                *
************************************************************************
      PHI = ((R1(1)*R2(1))+(R1(2)*R2(2))+(R1(3)*R2(3)))/(R1(4)*R2(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R1(4)))+(DACOS(1.0D0/R2(4)))-(DACOS(PHI))
      WRITE(10,110)COUNT*SIZE,VIS

   20 CONTINUE

      CLOSE(UNIT=1)
      CLOSE(UNIT=2)
      CLOSE(UNIT=10)
```

```
  110 FORMAT(I10,5X,F12.5)
      END
*
```

```
*                    SUBROUTINE THRVIS                                  *
*                                                                       *
*   PURPOSE:  This subroutine examines the visibility opportunities     *
*             between three satellites.                                 *
*                                                                       *
*  VARIABLES:                                                           *
*   INPUT:                                                              *
*     STEPS     - number of steps in the requested interval             *
*     SIZE      - step size (SEC)                                       *
*                                                                       *
*  LOCAL VARIABLES:                                                     *
*     COUNT     - DO loop counter                                       *
*     PHI       - angle between position vectors to two satellites      *
*     R1        - position vector to satellite #1                       *
*     R2        - position vector to satellite #2                       *
*     R3        - position vector to satellite #3                       *
*     VIS       - visibility function between two satellites            *
************************************************************************
      SUBROUTINE THRVIS(STEPS,SIZE)

      INTEGER COUNT,STEPS
      REAL*8  PHI,R1(4),R2(4),R3(4),SIZE,VIS

      OPEN(UNIT=1,FILE='POS1.DAT',STATUS='OLD')
      OPEN(UNIT=2,FILE='POS2.DAT',STATUS='OLD')
      OPEN(UNIT=3,FILE='POS3.DAT',STATUS='OLD')
************************************************************************
*  The following table lists filenames and their content               *
*     UNIT = 10; VIS1.DAT   - visibility between 1 and 2               *
*     UNIT = 11; VIS2.DAT   - visibility between 1 and 3               *
*     UNIT = 12; VIS3.DAT   - visibility between 2 and 3               *
************************************************************************
      OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='NEW')
      OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='NEW')
      OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='NEW')

      DO 20 COUNT = 0,STEPS
         READ(1,*)R1(1),R1(2),R1(3),R1(4)
         READ(2,*)R2(1),R2(2),R2(3),R2(4)
         READ(3,*)R3(1),R3(2),R3(3),R3(4)
************************************************************************
*  The following lines calculate the visibility function as explained  *
*  in the subroutine TWOVIS.  Since three satellites are involved in   *
*  this case, visibility checks must be made between satellites 1 and  *
*  2, 2 and 3, and 1 and 3.                                            *
************************************************************************
*                 Satellites #1 and #2                                  *
************************************************************************
      PHI = ((R1(1)*R2(1))+(R1(2)*R2(2))+(R1(3)*R2(3)))/(R1(4)*R2(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R1(4))) + (DACOS(1.0D0/R2(4))) - (DACOS(PHI))
      WRITE(10,110)COUNT*SIZE,VIS
************************************************************************
*                 Satellites #1 and #3                                  *
************************************************************************
      PHI = ((R1(1)*R3(1))+(R1(2)*R3(2))+(R1(3)*R3(3)))/(R1(4)*R3(4))
```

```
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R1(1))) + (DACOS(1.0D0/R3(1))) - (DACOS(PHI))
      WRITE(11,110)COUNT*SIZE,VIS
*************************************************************************
*                  Satellites #2 and #3                                 *
*************************************************************************
      PHI = ((R2(1)*R3(1))+(R2(2)*R3(2))+(R2(3)*R3(3)))/(R2(4)*R3(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R2(1)))+(DACOS(1.0D0/R3(1)))-(DACOS(PHI))
      WRITE(12,110)COUNT*SIZE,VIS

   20 CONTINUE

      CLOSE(UNIT = 1)
      CLOSE(UNIT = 2)
      CLOSE(UNIT = 3)
      CLOSE(UNIT = 10)
      CLOSE(UNIT = 11)
      CLOSE(UNIT = 12)

      RETURN

  110 FORMAT(I10,3X,F12.3)

      END
*
```

```
*                    SUBROUTINE FOURVIS                                 *
*                                                                       *
*   PURPOSE:  This subroutine examines the visibility opportunities     *
*             between four satellites.                                  *
*                                                                       *
*  VARIABLES:                                                           *
*   INPUT:                                                              *
*     STEPS     - number of steps in the requested interval             *
*     SIZE      - step size (SEC)                                       *
*                                                                       *
*  LOCAL VARIABLES:                                                     *
*     COUNT     - DO loop counter                                       *
*     PHI       - angle between position vectors to two satellites      *
*     R1        - position vector to satellite #1                       *
*     R2        - position vector to satellite #2                       *
*     R3        - position vector to satellite #3                       *
*     R4        - position vector to satellite #4                       *
*     VIS       - visibility function between two satellites            *
************************************************************************
      SUBROUTINE FOURVIS(STEPS,SIZE)

      INTEGER COUNT,STEPS
      REAL*8  PHI,R1(4),R2(4),R3(4),R4(4),SIZE,VIS

      OPEN(UNIT=1,FILE='POS1.DAT',STATUS='OLD')
      OPEN(UNIT=2,FILE='POS2.DAT',STATUS='OLD')
      OPEN(UNIT=3,FILE='POS3.DAT',STATUS='OLD')
      OPEN(UNIT=4,FILE='POS4.DAT',STATUS='OLD')
************************************************************************
*  The following table lists filenames and their content               *
*     UNIT = 10; VIS1.DAT   - visibility between 1 and 2               *
*     UNIT = 11; VIS2.DAT   - visibility between 1 and 3               *
*     UNIT = 12; VIS3.DAT   - visibility between 1 and 4               *
*     UNIT = 13; VIS4.DAT   - visibility between 2 and 3               *
*     UNIT = 14; VIS5.DAT   - visibility between 2 and 4               *
*     UNIT = 15; VIS6.DAT   - visibility between 3 and 4               *
************************************************************************
      OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='NEW')
      OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='NEW')
      OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='NEW')
      OPEN(UNIT=13,FILE='VIS4.DAT',STATUS='NEW')
      OPEN(UNIT=14,FILE='VIS5.DAT',STATUS='NEW')
      OPEN(UNIT=15,FILE='VIS6.DAT',STATUS='NEW')

      DO 20 COUNT = 0,STEPS
         READ(1,*)R1(1),R1(2),R1(3),R1(4)
         READ(2,*)R2(1),R2(2),R2(3),R2(4)
         READ(3,*)R3(1),R3(2),R3(3),R3(4)
         READ(4,*)R4(1),R4(2),R4(3),R4(4)
************************************************************************
*  The following lines calculate the visibility function as explained  *
*  in the subroutine TWOVIS.  Since four satellites are involved in    *
*  this case, visibility checks must be made between satellites 1 and  *
*  2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4.                 *
************************************************************************
*                  Satellites #1 and #2                                *
************************************************************************
      PHI = ((R1(1)*R2(1))+(R1(2)*R2(2))+(R1(3)*R2(3)))/(R1(4)*R2(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
```

```
*************************************************************************
*                  Satellites #1 and #3                                 *
*************************************************************************
      PHI = ((R1(1)*R3(1))+(R1(2)*R3(2))+(R1(3)*R3(3)))/(R1(4)*R3(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R1(4))) + (DACOS(1.0D0/R3(4))) - (DACOS(PHI))
      WRITE(11,110)COUNT*SIZE,VIS
*************************************************************************
*                  Satellites #1 and #4                                 *
*************************************************************************
      PHI = ((R1(1)*R4(1))+(R1(2)*R4(2))+(R1(3)*R4(3)))/(R1(4)*R4(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R1(4))) + (DACOS(1.0D0/R4(4))) - (DACOS(PHI))
      WRITE(12,110)COUNT*SIZE,VIS
*************************************************************************
*                  Satellites #2 and #3                                 *
*************************************************************************
      PHI = ((R2(1)*R3(1))+(R2(2)*R3(2))+(R2(3)*R3(3)))/(R2(4)*R3(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R2(4)))+(DACOS(1.0D0/R3(4)))-(DACOS(PHI))
      WRITE(13,110)COUNT*SIZE,VIS
*************************************************************************
*                  Satellites #2 and #4                                 *
*************************************************************************
      PHI = ((R2(1)*R4(1))+(R2(2)*R4(2))+(R2(3)*R4(3)))/(R2(4)*R4(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF

      VIS = (DACOS(1.0D0/R2(4)))+(DACOS(1.0D0/R4(4)))-(DACOS(PHI))
      WRITE(14,110)COUNT*SIZE,VIS
*************************************************************************
*                  Satellites #3 and #4                                 *
*************************************************************************
      PHI = ((R3(1)*R4(1))+(R3(2)*R4(2))+(R3(3)*R4(3)))/(R3(4)*R4(4))

      IF (PHI.GT.(1.0D0)) THEN
         PHI = 1.0D0
      ELSE IF (PHI.LT.(-1.0D0)) THEN
         PHI = -1.0D0
      ENDIF
```

```
      WRITE(15,110)COUNT*SIZE,VIS

   20 CONTINUE

      CLOSE(UNIT = 1)
      CLOSE(UNIT = 2)
      CLOSE(UNIT = 3)
      CLOSE(UNIT = 4)
      CLOSE(UNIT = 10)
      CLOSE(UNIT = 11)
      CLOSE(UNIT = 12)
      CLOSE(UNIT = 13)
      CLOSE(UNIT = 14)
      CLOSE(UNIT = 15)

      RETURN

  110 FORMAT(I10,5X,F12.5)

      END
*
```

```
                        SUBROUTINE BLEND                                *
*                                                                       *
*  PURPOSE:  The purpose of this subroutine is to parabolically blend   *
*            the points of the visibility function.  The equation of    *
*            the blended curve will then be solved for real roots. If   *
*            a real root exists, it represents either a rise or set     *
*            time for the objects of interest.                          *
*                                                                       *
*  VARIABLES:                                                           *
*   INPUT:                                                              *
*     STATE    - specifies a file unit number                           *
*     STEPS    - number of steps                                        *
*     T        - chronological time over time span                      *
*     VIS      - value of the visibility function                       *
*                                                                       *
*  LOCAL VARIABLES:                                                     *
*     A,B      - variables used in the solution of the closed form      *
*                cubic equation (Escobal, 432-434)                      *
*     ALPHA    - coefficients of the cubic                              *
*     CHECK    - slightly later time than cross.  The value of check    *
*                is used to determine is a horizon crossing is a        *
*                rise or set.                                           *
*     COSPHI   - cosine of the angle phi used in solution of the        *
*                cubic equation                                         *
*     COUNT    - do loop counter
*     CROSS    - time of a rise or set                                  *
*     D120     - 120 DEG changed to radians                             *
*     D240     - 240 DEG changed to radians                             *
*     DELTA    - see closed form solution of cubic equation             *
*     EVENT    - 1 if the crossing is a rise; 0 if the crossing is a    *
*                set                                                    *
*     EO       - see closed form solution of cubic equation             *
*     INC      - increment of time T                                    *
*     O        - coefficient of cubed variable in cubic equation        *
*     P        - coefficient of squared variable in cubic equation      *
*     PHI      - angle used in calculation of roots of cubic equation   *
*     PI       - mathematical constant pi                               *
*     Q        - coefficient of the  first degree variable in the       *
*                cubic equation                                         *
*     QTNT     - portion of the quadratic equation under the radical    *
*     R        - constant value in the cubic equation                   *
*     ROOT1,ROOT2,ROOT3 - possible roots of the cubic equation          *
*     SINPHI   - sine of the angle phi used in solution of the cubic    *
*                equation                                               *
*    Z1,Z2,Z3  - variables used in determining roots of the cubic       *
*                equation                                               *
*                                                                       *
*    REFERENCES: Adams and Rogers, 278-284                              *
*                Alfano, Negron, and Moore, 4-5                         *
*                Escobal, 431-433                                       *
*************************************************************************
      SUBROUTINE BLEND(STATE,STEPS,T,VIS)

      INTEGER COUNT,STATE,STEPS
      REAL*8  A,ARG1,ARG2,B,ALP2(0:3),ALPHA(0:3),CHECK,COSPHI,CROSS
      REAL*8  D120,D240,DELTA,EO,EVENT,INC,P,PHI,PI,Q,QTNT,VALA,VALB
      REAL*8  R,ROOT1,ROOT2,ROOT3,SINPHI,T(0:STEPS+2)
      REAL*8  VIS(0:STEPS+2),Z1,Z2,Z3
*************************************************************************
*                  CONSTANTS                                            *
*************************************************************************
      PI    = DACOS(-1.0D0)
      D120 = 120.0D0*(PI/180.0D0)
```

```
*  The following lines assign values to the first and last points in  *
*  in the visibility curve.  These points fall immediately before and *
*  immediately after the endpoints of interest.  This insures no      *
*  portion of the curve will be omitted when testing for horizon      *
*  crossings.
*********************************************************************
      T(0)   = T(1)
      VIS(0) = VIS(1)
      T(STEPS+2)   = T(STEPS+1)
      VIS(STEPS+2) = VIS(STEPS+1)
*********************************************************************
*  In the following do loop, the coefficients of the cubic equation  *
*  are determined using parabolic blending.                          *
*********************************************************************
      DO 10 COUNT = 1,STEPS
         ALPHA(3) = (-.50D0)*VIS(COUNT-1)+(1.50D0)*VIS(COUNT)+(-1.50D0)*
     +              VIS(COUNT+1)+(.50D0)*VIS(COUNT+2)
         ALPHA(2) = VIS(COUNT-1)+(-2.50D0)*VIS(COUNT)+(2.0D0)*
     +              VIS(COUNT+1)+(-.50D0)*VIS(COUNT+2)
         ALPHA(1) = (-.50D0)*VIS(COUNT-1)+(.5D0)*VIS(COUNT+1)
         ALPHA(0) = VIS(COUNT)
*********************************************************************
*  In the event that the equation is a quadratic equation instead of  *
*  a cubic equation, the following lines determine the roots of the   *
*  quadratic.
*********************************************************************
         IF (DABS(ALPHA(3)).LE.(0.000001D0).AND.DABS(ALPHA(2)).LE.
     +  (0.000001D0).AND.DABS(ALPHA(1)).LT.(.000001D0)) THEN
            ROOT1 = -1.0D0
            ROOT2 = -1.0D0
            ROOT3 = -1.0D0
            GOTO 5
         ELSE IF (DABS(ALPHA(3)).LE.(0.000001D0).AND.DABS(ALPHA(2)).LE.
     +  (0.000001D0)) THEN
            ROOT1 = -ALPHA(0)/ALPHA(1)
            ROOT2 = -1.0D0
            ROOT3 = -1.0D0
            GOTO 5
         ELSE IF (DABS(ALPHA(3)).LE.(0.000001D0)) THEN
            QINT = (ALPHA(1)**2.0D0)-(4.0D0*ALPHA(2)*ALPHA(0))
            IF (QINT.GE.(0.0D0)) THEN
               ROOT1 = (-ALPHA(1)+DSQRT(QINT))/(2.0D0*ALPHA(2))
               ROOT2 = (-ALPHA(1)-DSQRT(QINT))/(2.0D0*ALPHA(2))
               ROOT3 = -1.0D0
               GOTO 5
            ELSE
               ROOT1 = -1.0D0
               ROOT2 = -1.0D0
               ROOT3 = -1.0D0
               GOTO 5
            ENDIF
         ENDIF
*********************************************************************
*  The following is a closed form solution to the cubic equation..   *
*********************************************************************
         P = ALPHA(2)/ALPHA(3)
         Q = ALPHA(1)/ALPHA(3)
         R = ALPHA(0)/ALPHA(3)
         A = (1.0D0/3.0D0)*((3.0D0*Q) - (P**2.0D0))
         B = (1.0D0/27.0D0)*((2.0D0*(P**3.0D0))-(9.0D0*P*Q)+(27.0D0*R))
         DELTA = ((A**3.0D0)/27.0D0) + ((B**2.0D0)/4.0D0)

         IF (DELTA.GT.(0.0D0)) THEN
```

```
            IF (ARG1.LT.(0.0D0)) THEN
               VALA = -((DABS(ARG1))**(.33333D0))
            ELSE
               VALA = ARG1**(.33333D0)
            ENDIF

            IF (ARG2.LT.(0.0D0)) THEN
               VALB = -((DABS(ARG2))**(.33333D0))
            ELSE
               VALB = ARG2**(.33333D0)
            ENDIF

            Z1    = VALA + VALB
            ROOT1 = Z1 - (P/3.0D0)
            ROOT2 = -1.0D0
            ROOT3 = -1.0D0
         ELSE IF (DELTA.EQ.(0.0D0)) THEN
            ARG1 = -B/2.0D0
            ARG2 =  B/2.0D0

            IF (ARG1.LT.(0.0D0)) THEN
               Z1 = -2.0D0*((DABS(ARG1))**(.33333D0))
            ELSE IF (ARG1.GT.(0.0D0)) THEN
               Z1 = 2.0D0*((DABS(ARG1))**(.33333D0))
            ENDIF

            IF (ARG2.LT.(0.0D0)) THEN
               Z2 = -((DABS(ARG2  **(.33333D0))
            ELSE IF (ARG2.GT.(0.0D0)) THEN
               Z2 = ARG2**(.33333D0)
            ENDIF
            ROOT1 = Z1 - (P/3.0D0)
            ROOT2 = Z2 - (P/3.0D0)
            ROOT3 = -1.0D0
         ELSE IF (DELTA.LT.(0.0D0)) THEN
            ARG1 = -(A**3.0D0)/27.0D0
            ARG2 = -(A/3.0D0)

         IF (ARG1.LT.(0.0D0).OR.ARG2.LT.(0.0D0)) THEN
            ROOT1 = -1.0D0
            ROOT2 = -1.0D0
            ROOT3 = -1.0D0
         ELSE
            EO = 2.0D0*DSQRT(ARG2)
            COSPHI = -B/(2.0D0*DSQRT(ARG1))
            SINPHI = DSQRT(1.0D0-(COSPHI**2.0D0))
            PHI    = DATAN2(SINPHI,COSPHI)
            Z1  = EO*DCOS(PHI/3.0D0)
            Z2  = EO*DCOS((PHI/3.0D0)+D120)
            Z3  = EO*DCOS((PHI/3.0D0)+D240)

            ROOT1 = Z1 - (P/3.0D0)
            ROOT2 = Z2 - (P/3.0D0)
            ROOT3 = Z3 - (P/3.0D0)
         ENDIF
      ENDIF
    5 CONTINUE
*************************************************************************
*  If a positive root is found, parabolic blending is used to deter-   *
*  a cubic equation based on the times corresponding to the visibility*
*  values of interest.  The value of this cubic equation evaluated at *
*  the root of the equation above (ROOT1,ROOT2, or ROOT3 above) to     *
*  find the exact time of crossing.  The same equation is evaluated    *
```

```
      IF (ROOT1.GE.0.AND.ROOT1.LE.1) THEN
         ALP2(3) = (-.50D0)*T(COUNT-1)+(1.50D0)*T(COUNT)+(-1.50D0)*
     +             T(COUNT+1)+(.50D0)*T(COUNT+2)
         ALP2(2) = T(COUNT-1)+(-2.50D0)*T(COUNT)+(2.0D0)*
     +             T(COUNT+1)+(-.50D0)*T(COUNT+2)
         ALP2(1) = (-.50D0)*T(COUNT-1)+(.5D0)*T(COUNT+1)
         ALP2(0) = T(COUNT)

         CROSS = ((ROOT1**3.0D0)*ALP2(3))+((ROOT1**2.0D0)*ALP2(2))+
     +           (ROOT1*ALP2(1))+ALP2(0)
         ROOT1 = ROOT1+INC
         CHECK = ((ROOT1**3.0D0)*ALPHA(3))+((ROOT1**2.0D0)*ALPHA(2))+
     +           (ROOT1*ALPHA(1))+ALPHA(0)
         IF (CROSS.GE.(T(COUNT)).AND.CROSS.LE.(T(COUNT+1))) THEN
            IF (CHECK.GT.(0.0D0)) THEN
               WRITE(25,100)CROSS
               EVENT = 1.0D0
               WRITE(60,*)CROSS,EVENT
               WRITE(STATE,*)CROSS,EVENT
            ELSE
               WRITE(25,110)CROSS
               EVENT = 0.0D0
               WRITE(60,*)CROSS,EVENT
               WRITE(STATE,*)CROSS,EVENT
            ENDIF
         ENDIF
      ENDIF

      IF (ROOT2.GE.0.AND.ROOT2.LE.1) THEN
         ALP2(3) = (-.50D0)*T(COUNT-1)+(1.50D0)*T(COUNT)+(-1.50D0)*
     +             T(COUNT+1)+(.50D0)*T(COUNT+2)
         ALP2(2) = T(COUNT-1)+(-2.50D0)*T(COUNT)+(2.0D0)*
     +             T(COUNT+1)+(-.50D0)*T(COUNT+2)
         ALP2(1) = (-.50D0)*T(COUNT-1)+(.5D0)*T(COUNT+1)
         ALP2(0) = T(COUNT)

         CROSS = ((ROOT2**3)*ALP2(3))+((ROOT2**2)*ALP2(2))+(ROOT2*
     +           ALP2(1))+ALP2(0)
         ROOT2 = ROOT2+INC
         CHECK = ((ROOT2**3)*ALPHA(3))+((ROOT2**2)*ALPHA(2))+(ROOT2*
     +           ALPHA(1))+ALPHA(0)
         IF (CROSS.GE.(T(COUNT)).AND.CROSS.LE.(T(COUNT+1))) THEN
            IF (CHECK.GT.(0.0D0)) THEN
               WRITE(25,100)CROSS
               EVENT = 1.0D0
               WRITE(60,*)CROSS,EVENT
               WRITE(STATE,*)CROSS,EVENT
            ELSE
               WRITE(25,110)CROSS
               EVENT = 0.0D0
               WRITE(60,*)CROSS,EVENT
               WRITE(STATE,*)CROSS,EVENT
            ENDIF
         ENDIF
      ENDIF

      IF (ROOT3.GE.0.AND.ROOT3.LE.1) THEN
         ALP2(3) = (-.50D0)*T(COUNT-1)+(1.50D0)*T(COUNT)+(-1.50D0)*
     +             T(COUNT+1)+(.50D0)*T(COUNT+2)
         ALP2(2) = T(COUNT-1)+(-2.50D0)*T(COUNT)+(2.0D0)*
     +             T(COUNT+1)+(-.50D0)*T(COUNT+2)
         ALP2(1) = (-.50D0)*T(COUNT-1)+(.5D0)*T(COUNT+1)
```

```
     +            ALP2(1))+ALP2(0)
          ROOT3 = ROOT3+INC
          CHECK = ((ROOT3**3)*ALPHA(3))+((ROOT3**2)*ALPHA(2))+(ROOT3*
     +            ALPHA(1))+ALPHA(0)
          IF (CROSS.GE.(T(COUNT)).AND.CROSS.LE.(T(COUNT+1))) THEN
             IF (CHECK.GT.(0.0D0)) THEN
                WRITE(25,100)CROSS
                EVENT = 1.0D0
                WRITE(60,*)CROSS,EVENT
                WRITE(STATE,*)CROSS,EVENT
             ELSE
                WRITE(25,110)CROSS
                EVENT = 0.0D0
                WRITE(60,*)CROSS,EVENT
                WRITE(STATE,*)CROSS,EVENT
             ENDIF
          ENDIF
       ENDIF

    10 CONTINUE

   100 FORMAT(F12.5,' SEC - RISE')
   110 FORMAT(F12.5,' SEC - SET')

       RETURN
       END
*
```

```
*                    SUBROUTINE GSSCVC2                                *
*                                                                      *
*  PURPOSE:  The purpose of this subroutine is to accomplish a         *
*            check for constant visibility between a ground station    *
*            and 2 satellites.                                         *
*                                                                      *
*  VARIABLES:                                                          *
*    INPUT:                                                            *
*      STATE     - File number specifier                               *
*                                                                      *
*    LOCAL VARIABLES:                                                  *
*      CHANGE    - specifies when communcation is broken or re-        *
*                  established                                         *
*      COUNT     - do loop counter                                     *
*      E1,E2     - Specifies rise/set time for visibility function     *
*                  a ground station and 2 satellites                   *
*      EVENT     - Array of all rise/set times                         *
*      IN        - do loop counter                                     *
*      RS1,RS2   - 1 if the event is a rise; 0 if the event is a set   *
*      SUM       - Sum of RS1 and RS2 at a given event                 *
*      T         - time zero of any selected visibility function       *
*                  - in this subroutine T is a place holder            *
*      TEMP      - Temporary value used in sort loop                   *
*      TOTAL     - Total number of events                              *
*      TOT1      - Number of events between Ground Station #? and      *
*                  Satellite #1                                        *
*      TOT2      - Number of events between Ground Station #? and      *
*                  Satellite #2                                        *
*      TT        - Holds all event times and the corresponding         *
*                  status of the visibility function for each          *
*                  viewing path                                        *
*      V         - the first value of the selected visibility          *
*                  function                                            *
*      X         - do loop counter                                     *
************************************************************************
      SUBROUTINE GSSCVC2(STATE)

      REAL*8  E1(0:100),E2(0:100),EVENT(0:500)
      REAL*8  RS1(0:100),RS2(0:100),SUM,T,TEMP,TT(0:500,2),V
      INTEGER COUNT,CHANGE,CHECK,IN,STATE,TOTAL,TOT1,TOT2,X

      OPEN(UNIT=41,FILE='STAT1.DAT',STATUS='OLD')
      OPEN(UNIT=42,FILE='STAT2.DAT',STATUS='OLD')
      OPEN(UNIT=60,FILE='TRACKER.DAT',STATUS='OLD')

      REWIND(UNIT=60)

      OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='OLD')
      OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='OLD')

      WRITE(*,*)'The computer is in the process of determining whether'
      WRITE(*,*)'or not continuous communications is possible.  When  '
      WRITE(*,*)'the program is finished runni   results can be found'
      WRITE(*,*)'in the file RISESET.DAT.'

************************************************************************
*              GROUND STATION AND SATELLITE #1                         *
************************************************************************
      TOT1 = 0
      DO 20 COUNT = 1,100
         READ(STATE,*,END=25)E1(COUNT),RS1(COUNT)
         TOT1 = COUNT
   20 CONTINUE
```

```
         READ(10,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS1(0) = 1.0D0
         ELSE
            RS1(0) = 0.0D0
         ENDIF
      ELSE IF (RS1(1).EQ.(0.0D0)) THEN
         RS1(0) = 1.0D0
      ELSE
         RS1(0) = 0.0D0
      ENDIF
*****************************************************************
*              GROUND STATION AND SATELLITE #2                  *
*****************************************************************
      TOT2 = 0
      DO 30 COUNT = 1,100
         READ(STATE+1,*,END=35)E2(COUNT),RS2(COUNT)
         TOT2 = COUNT
   30 CONTINUE
   35 E2(0) = 0.0D0

      IF (TOT2.EQ.0) THEN
         READ(11,*)T,V
            IF (V.GT.(0.0D0)) THEN
               RS2(0) = 1.0D0
            ELSE
               RS2(0) = 0.0D0
            ENDIF
      ELSE IF (RS2(1).EQ.(0.0D0)) THEN
         RS2(0) = 1.0D0
      ELSE
         RS2(0) = 0.0D0
      ENDIF
*****************************************************************
*  The following calculates the total number of events between the  *
*  ground station and two satellites.                             *
*****************************************************************
      TOTAL = TOT1+TOT2

      CHECK = 0
      DO 45 COUNT = 1,500
         READ(60,*,END=48)EVENT(COUNT)
         CHECK = COUNT
   45 CONTINUE
   48 CONTINUE

      IF (CHECK.EQ.0) THEN
         WRITE(25,*)'There were no visibility opportunities with this
     + configuration.'
         GOTO 140
      ENDIF
*****************************************************************
*  The following orders all the events from the smallest to the   *
*  largest.                                                       *
*****************************************************************
      DO 60 COUNT = 1,TOTAL-1
         DO 50 X = 1,TOTAL-1
            IF (EVENT(X+1).LT.EVENT(X)) THEN
               TEMP     = EVENT(X+1)
               EVENT(X+1) = EVENT(X)
               EVENT(X)   = TEMP
            ENDIF
   50 CONTINUE
```

```
*****************************************************************
*  The following determines the status of communications for each  *
*  possible visibility path at each event.                        *
*****************************************************************
      DO 80 COUNT = 0,TOTAL
            IF (TOT1.EQ.0) THEN
               TT(COUNT,1) = RS1(0)
               GOTO 80
            ENDIF
         DO 70 IN = 0,TOT1 - 1
          IF (EVENT(COUNT).GE.E1(IN).AND.EVENT(COUNT).LT.E1(IN+1)) THEN
             TT(COUNT,1) = RS1(IN)
             GOTO 80
          ELSE IF (EVENT(COUNT).EQ.E1(IN+1)) THEN
             TT(COUNT,1) = RS1(IN+1)
             GOTO 80
          ELSE IF (EVENT(COUNT).GT.E1(IN+1).AND.IN.EQ.(TOT1-1)) THEN
             TT(COUNT,1) = RS1(IN+1)
             GOTO 80
          ENDIF
   70 CONTINUE
   80 CONTINUE

      DO 120 COUNT = 0,TOTAL
            IF (TOT2.EQ.0) THEN
               TT(COUNT,2) = RS2(0)
               GOTO 120
            ENDIF
         DO 110 IN = 0,TOT2 - 1
          IF (EVENT(COUNT).GE.E2(IN).AND.EVENT(COUNT).LT.E2(IN+1)) THEN
             TT(COUNT,2) = RS2(IN)
             GOTO 120
          ELSE IF (EVENT(COUNT).EQ.E2(IN+1)) THEN
             TT(COUNT,2) = RS2(IN+1)
             GOTO 120
          ELSE IF (EVENT(COUNT).GT.E2(IN+1).AND.IN.EQ.(TOT2-1)) THEN
             TT(COUNT,2) = RS2(IN+1)
             GOTO 120
          ENDIF
  110 CONTINUE
  120 CONTINUE

      CHANGE = 1
*****************************************************************
*  The next DO loop determines if constant communication is       *
*  possible.  If the sum is equal to zero, communication is not   *
*  possible.  If the sum is greater than or equal to one, communi-*
*  cation is possible.                                            *
*****************************************************************
      DO 130 COUNT = 0,TOTAL
         SUM = TT(COUNT,1) + TT(COUNT,2)
         IF (SUM.EQ.(0.0D0).AND.CHANGE.EQ.1) THEN
            WRITE(25,*)'Communications broken at ',EVENT(COUNT)
            CHANGE = 0
         ENDIF

         IF (SUM.GE.(1.0D0).AND.CHANGE.EQ.0) THEN
            WRITE(25,*)'Communications re-established at ',EVENT(COUNT)
            CHANGE = 1
         ENDIF
  130 CONTINUE
  140 CONTINUE
```

```
      CLOSE(UNIT=10,STATUS='DELETE')
      CLOSE(UNIT=11,STATUS='DELETE')

      RETURN
      END
*
```

```
*****************************************************************
*                      SUBROUTINE CVC3                          *
*                                                               *
*  PURPOSE:  The purpose of this subroutine is to accomplish a  *
*            check for constant visibility between 3 satellites.*
*            For visibility to be maintained, at least two      *
*            paths of visibility must be maintained at all times.*
*                                                               *
*  VARIABLES:                                                   *
*    INPUT:                                                     *
*      KIND      - specifies whether 3 satellites are involved (1)*
*                  or a ground station and 3 satellites are     *
*                  involved (0)                                 *
*      STATE     - File number specifier                        *
*                                                               *
*    LOCAL VARIABLES:                                           *
*      CHANGE    - specifies when communcation is broken or re- *
*                  established                                  *
*      CCOUNT    - do loop counter                              *
*      E1,..,E3  - Specifies rise/set time for visibility function*
*                  between 3 satellites or a ground station and *
*                  3 satellites                                 *
*      EVENT     - Array of all rise/set times                  *
*      IN        - do loop counter                              *
*      RS1,..RS3 - 1 if the event is a rise; 0 if the event is a set*
*      SUM       - Sum of RS1...RS3 at a given event            *
*      T         - time zero read from file of visibility data  *
*                  - in this subroutine, T serves only as a place*
*                    holder                                     *
*      TEMP      - Temporary value used in sort loop            *
*      TOTAL     - Total number of events                       *
*      TOT1      - Number of events between Satellite #1 and    *
*                  Satellite #2 or Ground Station #? and        *
*                  Satellite #1                                 *
*      TOT2      - Number of events between Satellite #2 and    *
*                  Satellite #3 or Ground Station #? and        *
*                  Satellite #2                                 *
*      TOT3      - Number of events between Satellite #1 and    *
*                  Satellite #3 or Ground Station #? and        *
*                  Satellite #3                                 *
*      TT        - Holds all event times and the corresponding  *
*                  status of the visibility function for each   *
*                  viewing path                                 *
*      V         - value of the chosen visibility function at time*
*                  equal to zero                                *
*      X         - do loop counter                              *
*****************************************************************
      SUBROUTINE CVC3(KIND,STATE)

      REAL*8  E1(0:100),E2(0:100),E3(0:100),EVENT(0:500),RS1(0:100)
      REAL*8  RS2(0:100),RS3(0:100),SUM,T,TEMP,TT(0:500,3),V
      INTEGER CHANGE,CCOUNT,IN,KIND,STATE,TOTAL,TOT1,TOT2,TOT3,X

      IF (KIND.EQ.1) THEN
         WRITE(*,*)
         WRITE(*,*)'The computer is in the process of determining'
         WRITE(*,*)'whether or not constant communications is '
         WRITE(*,*)'maintained.  When the program has finished'
         WRITE(*,*)'running, results may be found in RISESET.DAT.'
      ENDIF

      OPEN(UNIT=41,FILE='STAT1.DAT',STATUS='OLD')
```

```
      OPEN(UNIT=60,FILE='TRACKER.DAT',STATUS='OLD')

      IF (KIND.EQ.0) THEN
         REWIND(UNIT=60)
      ENDIF

      OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='OLD')
      OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='OLD')
      OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='OLD')
*************************************************************************
*  The following DO loops read the rise and set times for each vis-     *
*  ibility path.                                                        *
*************************************************************************
*              SATELLITE #1 AND SATELLITE #2                            *
*             GROUND STATION AND SATELLITE #1                           *
*************************************************************************
      TOT1 = 0
      DO 20 COUNT = 1,100
         READ(STATE,*,END=25)E1(COUNT),RS1(COUNT)
         TOT1 = COUNT
   20 CONTINUE
   25 E1(0) = 0.0D0
*************************************************************************
*  If there were no rise or set times, the file containing the vis-     *
*  ibility data must be referenced to determine if the two objects      *
*  of interest are always in view or never in view.                     *
*************************************************************************
      IF (TOT1.EQ.0) THEN
            READ(10,*)T,V
            IF (V.GT.(0.0D0)) THEN
               RS1(0)=1.0D0
            ELSE
               RS1(0)=0.0D0
            ENDIF
*************************************************************************
*  The following line checks the first condition of the first rise      *
*  or set time then assigns the appropriate condition to time zero.     *
*************************************************************************
         ELSE IF (RS1(1).EQ.(0.0D0)) THEN
            RS1(0) = 1.0D0
         ELSE
            RS1(0) = 0.0D0
      ENDIF
*************************************************************************
*              SATELLITE #1 AND SATELLITE #3                            *
*             GROUND STATION AND SATELLITE #2                           *
*************************************************************************
      TOT2 = 0
      DO 30 COUNT = 1,100
         READ(STATE+1,*,END=35)E2(COUNT),RS2(COUNT)
         TOT2 = COUNT
   30 CONTINUE
   35 E2(0) = 0.0D0

      IF (TOT2.EQ.0) THEN
         READ(11,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS2(0)=1.0D0
         ELSE
            RS2(0)=0.0D0
         ENDIF
*************************************************************************
*  The following line checks the first condition of the first rise      *
*  or set time then assigns the appropriate condition to time zero.     *
```

```
            RS2(0) = 1.0D0
         ELSE
            RS2(0) = 0.0D0
      ENDIF
*************************************************************************
*                SATELLITE #2 AND SATELLITE #3                          *
*              GROUND STATION AND SATELLITE #3                          *
*************************************************************************
      TOT3 = 0
      DO 40 COUNT = 1,100
         READ(STATE+2,*,END=45)E3(COUNT),RS3(COUNT)
         TOT3 = COUNT
   40 CONTINUE
   45 E3(0) = 0.0D0

      IF (TOT3.EQ.0) THEN
         READ(12,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS3(0)=1.0D0
         ELSE
            RS3(0)=0.0D0
         ENDIF
*************************************************************************
*  The following line checks the first condition of the first rise      *
*  or set time then assigns the appropriate condition to time zero.     *
*************************************************************************
         ELSE IF (RS3(1).EQ.(0.0D0)) THEN
            RS3(0) = 1.0D0
         ELSE
            RS3(0) = 0.0D0
      ENDIF
*************************************************************************
*  The following calculates the total number of rise/set events         *
*  between the ground station and the three satellites or between       *
*  the three satellites.                                                *
*************************************************************************
      TOTAL = TOT1+TOT2+TOT3

      DO 47 COUNT = 1,500
         READ(60,*,END=48)EVENT(COUNT)
   47 CONTINUE
   48 CONTINUE
*************************************************************************
*  If there were no rise/set times at all, the following message is     *
*  written to the final output file and the program ends.               *
*************************************************************************
      IF (COUNT.EQ.1) THEN
         WRITE(25,*)'There were no opportunities for viewing
     + wtih this configuration.'
         GOTO 215
      ENDIF
*************************************************************************
*  The following performs a sort to place the list of all events in     *
*  order from smallest number to largest.                               *
*************************************************************************
      DO 60 COUNT = 1,TOTAL-1
         DO 50 X = 1,TOTAL-1
            IF (EVENT(X+1).LT.EVENT(X)) THEN
               TEMP     = EVENT(X+1)
               EVENT(X+1) = EVENT(X)
               EVENT(X)   = TEMP
            ENDIF
   50 CONTINUE
   60 CONTINUE
```

```
*************************************************************************
*  The following loops determine the intermediate status of visibil-*
*  ity at each event.                                                   *
*************************************************************************
      DO 80 COUNT = 0,TOTAL
            IF (TOT1.EQ.0) THEN
               TT(COUNT,1) = RS1(0)
               GOTO 80
            ENDIF
         DO 70 IN = 0,TOT1 - 1
          IF (EVENT(COUNT).GE.E1(IN).AND.EVENT(COUNT).LT.E1(IN+1)) THEN
             TT(COUNT,1) = RS1(IN)
             GOTO 80
          ELSE IF (EVENT(COUNT).EQ.E1(IN+1)) THEN
             TT(COUNT,1) = RS1(IN+1)
             GOTO 80
          ELSE IF (EVENT(COUNT).GT.E1(IN+1).AND.IN.EQ.(TOT1-1)) THEN
             TT(COUNT,1) = RS1(TOT1)
             GOTO 80
          ENDIF
   70 CONTINUE
   80 CONTINUE

      DO 100 COUNT = 0,TOTAL
            IF (TOT2.EQ.0) THEN
               TT(COUNT,2) = RS2(0)
               GOTO 100
            ENDIF
         DO 90 IN = 0,TOT2 - 1
          IF (EVENT(COUNT).GE.E2(IN).AND.EVENT(COUNT).LT.E2(IN+1)) THEN
             TT(COUNT,2) = RS2(IN)
             GOTO 100
          ELSE IF (EVENT(COUNT).EQ.E2(IN+1)) THEN
             TT(COUNT,2) = RS2(IN+1)
             GOTO 100
          ELSE IF (EVENT(COUNT).GT.E2(IN+1).AND.IN.EQ.(TOT2-1)) THEN
             TT(COUNT,2) = RS2(TOT2)
             GOTO 100
          ENDIF
   90 CONTINUE
  100 CONTINUE

      DO 120 COUNT = 0,TOTAL
         DO 110 IN = 0,TOT3 - 1
          IF (EVENT(COUNT).GE.E3(IN).AND.EVENT(COUNT).LT.E3(IN+1)) THEN
             TT(COUNT,3) = RS3(IN)
             GOTO 120
          ELSE IF (EVENT(COUNT).EQ.E3(IN+1)) THEN
             TT(COUNT,3) = RS3(IN+1)
             GOTO 120
          ELSE IF (EVENT(COUNT).GT.E3(IN+1).AND.IN.EQ.(TOT3-1)) THEN
             TT(COUNT,3) = RS3(TOT3)
             GOTO 120
          ENDIF
  110 CONTINUE
  120 CONTINUE

      CHANGE = 1
*************************************************************************
*  The following determines if continuous communication is possible.*
*  For 3 satellites, the sum must be greater than or equal to 2.    *
*  For a ground station and three satellites, the sum must be       *
*  greater than or equal to 1.                                      *
*************************************************************************
      IF (KIND.EQ.1) THEN
```

```
            IF (SUM.LE.(1.0D0).AND.CHANGE.EQ.1) THEN
               WRITE(25,200)EVENT(COUNT)
               CHANGE = 0
            ENDIF

            IF (SUM.GE.(2.0D0).AND.CHANGE.EQ.0) THEN
               WRITE(25,210)EVENT(COUNT)
               CHANGE = 1
            ENDIF
  130 CONTINUE

      ELSE IF (KIND.EQ.0) THEN
         DO 140 COUNT = 0,TOTAL
            SUM = TT(COUNT,1) + TT(COUNT,2) + TT(COUNT,3)
            IF (SUM.LT.(1.0D0).AND.CHANGE.EQ.1) THEN
               WRITE(25,200)EVENT(COUNT)
               CHANGE = 0
            ENDIF

            IF (SUM.GE.(1.0D0).AND.CHANGE.EQ.0) THEN
               WRITE(25,210)EVENT(COUNT)
               CHANGE = 1
            ENDIF
  140 CONTINUE
      ENDIF

  215 CONTINUE

      CLOSE(UNIT=STATE,STATUS='DELETE')
      CLOSE(UNIT=STATE+1,STATUS='DELETE')
      CLOSE(UNIT=STATE+2,STATUS='DELETE')
      CLOSE(UNIT=60)
      CLOSE(UNIT=10,STATUS='DELETE')
      CLOSE(UNIT=11,STATUS='DELETE')
      CLOSE(UNIT=12,STATUS='DELETE')

  200 FORMAT('Communications broken at ',F12.5,' SEC')
  210 FORMAT('Communications re-established at ',F12.5,' SEC')

      RETURN

      END
*
```

```
*                    SUBROUTINE CVC4                                  *
*                                                                     *
*  PURPOSE:  The purpose of this subroutine is to accomplish a        *
*            check for constant visibility between 4 satellites.      *
*            For visibility to be maintained, at least 3              *
*            paths of visibility must be maintained at all times.     *
*                                                                     *
*  VARIABLES:                                                         *
*    INPUT:                                                           *
*      STATE     - File number specifier                             *
*                                                                     *
*    LOCAL VARIABLES:                                                 *
*      CHANGE    - specifies when communcation is broken or re-      *
*                  established                                        *
*      COUNT     - do loop counter                                   *
*      E1,..,E6  - Specifies rise/set time for visibility function   *
*                  between 6 satellites                               *
*      EVENT     - Array of all rise/set times                       *
*      IN        - do loop counter                                   *
*      RS1,..RS6 - 1 if the event is a rise; 0 if the event is a set*
*      SUM       - Sum of RS1...RS6 at a given event                 *
*      T         - time zero read from file of visibility data       *
*                  - in this subroutine, T serves only as a place    *
*                    holder                                           *
*      TEMP      - Temporary value used in sort loop                 *
*      TOTAL     - Total number of events                            *
*      TOT1      - Number of events between Satellite #1 and         *
*                  Satellite #2                                       *
*      TOT2      - Number of events between Satellite #1 and         *
*                  Satellite #3                                       *
*      TOT3      - Number of events between Satellite #1 and         *
*                  Satellite #4                                       *
*      TOT4      - Number of events between Satellite #2 and         *
*                  Satellite #3                                       *
*      TOT5      - Number of events between Satellite #2 and         *
*                  Satellite #4                                       *
*      TOT6      - Number of events between Satellite #3 and         *
*                  Satellite #4                                       *
*      TT        - Holds all event times and the corresponding       *
*                  status of the visibility function for each         *
*                  viewing path                                       *
*      V         - value of the chosen visibility function at time   *
*                  equal to zero                                      *
*      X         - do loop counter                                   *
**********************************************************************
      SUBROUTINE CVC4(STATE)

      REAL*8  E1(0:50),E2(0:50),E3(0:50),E4(0:50),E5(0:50)
      REAL*8  E6(0:50),EVENT(0:200),RS1(0:50),RS2(0:50),RS3(0:50)
      REAL*8  RS4(0:50),RS5(0:50),RS6(0:50),SUM,T,TEMP,TT(0:200,6),V
      INTEGER CHANGE,COUNT,IN,STATE,TOTAL,TOT1,TOT2,TOT3,TOT4,TOT5
      INTEGER TOT6,X

      WRITE(*,*)
      WRITE(*,*)'The computer is in the process of determining'
      WRITE(*,*)'whether or not constant communications is '
      WRITE(*,*)'maintained.  When the program has finished'
      WRITE(*,*)'running, results may be found in RISESET.DAT.'

      OPEN(UNIT=41,FILE='STAT1.DAT',STATUS='OLD')
      OPEN(UNIT=42,FILE='STAT2.DAT',STATUS='OLD')
      OPEN(UNIT=43,FILE='STAT3.DAT',STATUS='OLD')
      OPEN(UNIT=44,FILE='STAT4.DAT',STATUS='OLD')
```

```
      OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='OLD')
      OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='OLD')
      OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='OLD')
      OPEN(UNIT=13,FILE='VIS4.DAT',STATUS='OLD')
      OPEN(UNIT=14,FILE='VIS5.DAT',STATUS='OLD')
      OPEN(UNIT=15,FILE='VIS6.DAT',STATUS='OLD')
*************************************************************************
*              SATELLITE #1 AND SATELLITE #2                            *
*************************************************************************
      TOT1 = 0
      DO 20 COUNT = 1,100
         READ(STATE,*,END=25)E1(COUNT),RS1(COUNT)
         TOT1 = COUNT
   20 CONTINUE
   25 E1(0) = 0.0D0

      IF (TOT1.EQ.0) THEN
         READ(10,*)T,V
            IF (V.GT.(0.0D0)) THEN
               RS1(0)=1.0D0
            ELSE
               RS1(0)=0.0D0
            ENDIF
      ELSE IF (RS1(1).EQ.(0.0D0)) THEN
         RS1(0) = 1.0D0
      ELSE
         RS1(0) = 0.0D0
      ENDIF
*************************************************************************
*                SATELLITE #1 AND SATELLITE #3                          *
*************************************************************************
      TOT2 = 0
      DO 30 COUNT = 1,100
         READ(STATE+1,*,END=35)E2(COUNT),RS2(COUNT)
         TOT2 = COUNT
   30 CONTINUE
   35 E2(0) = 0.0D0

      IF (TOT2.EQ.0) THEN
         READ(11,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS2(0)=1.0D0
         ELSE
            RS2(0)=0.0D0
         ENDIF
      ELSE IF (RS2(1).EQ.(0.0D0)) THEN
         RS2(0) = 1.0D0
      ELSE
         RS2(0) = 0.0D0
      ENDIF
*************************************************************************
*                SATELLITE #1 AND SATELLITE #4                          *
*************************************************************************
      TOT3 = 0
      DO 40 COUNT = 1,100
         READ(STATE+2,*,END=45)E3(COUNT),RS3(COUNT)
         TOT3 = COUNT
   40 CONTINUE
   45 E3(0) = 0.0D0

      IF (TOT3.EQ.0) THEN
         READ(12,*)T,V
```

```
         ENDIF
*************************************************************************
*  The following line checks the first condition of the first rise  *
*  or set time then assigns the appropriate condition to time zero. *
*************************************************************************
      ELSE IF (RS3(1).EQ.(0.0D0)) THEN
         RS3(0) = 1.0D0
      ELSE
         RS3(0) = 0.0D0
      ENDIF
*************************************************************************
*                SATELLITE #2 AND SATELLITE #3                          *
*************************************************************************
      TOT4 = 0
      DO 50 COUNT = 1,100
         READ(STATE+3,*,END=55)E4(COUNT),RS4(COUNT)
         TOT4 = COUNT
   50 CONTINUE
   55 E4(0) = 0.0D0

      IF (TOT4.EQ.0) THEN
         READ(13,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS4(0)=1.0D0
         ELSE
            RS4(0)=0.0D0
         ENDIF
*************************************************************************
*  The following line checks the first condition of the first rise  *
*  or set time then assigns the appropriate condition to time zero. *
*************************************************************************
      ELSE IF (RS4(1).EQ.(0.0D0)) THEN
         RS4(0) = 1.0D0
      ELSE
         RS4(0) = 0.0D0
      ENDIF
*************************************************************************
*                SATELLITE #2 AND SATELLITE #4                          *
*************************************************************************
      TOT5 = 0
      DO 60 COUNT = 1,100
         READ(STATE+4,*,END=65)E5(COUNT),RS5(COUNT)
         TOT5 = COUNT
   60 CONTINUE
   65 E5(0) = 0.0D0

      IF (TOT5.EQ.0) THEN
         READ(14,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS5(0)=1.0D0
         ELSE
            RS5(0)=0.0D0
         ENDIF
*************************************************************************
*  The following line checks the first condition of the first rise  *
*  or set time then assigns the appropriate condition to time zero. *
*************************************************************************
      ELSE IF (RS5(1).EQ.(0.0D0)) THEN
         RS5(0) = 1.0D0
      ELSE
         RS5(0) = 0.0D0
      ENDIF
```

```
      DO 70 COUNT = 1,100
         READ(STATE+5,*,END=73)E6(COUNT),RS6(COUNT)
         TOT6 = COUNT
   70 CONTINUE
   73 E6(0) = 0.0D0

      IF (TOT6.EQ.0) THEN
         READ(15,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS6(0)=1.0D0
         ELSE
            RS6(0)=0.0D0
         ENDIF
*************************************************************************
*  The following line checks the first condition of the first rise  *
*  or set time then assigns the appropriate condition to time zero. *
*************************************************************************
      ELSE IF (RS6(1).EQ.(0.0D0)) THEN
         RS6(0) = 1.0D0
      ELSE
         RS6(0) = 0.0D0
      ENDIF
*************************************************************************
*  The following calculates the total number of rise/set events     *
*  between the ground station and the three satellites.             *
*************************************************************************
      TOTAL = TOT1+TOT2+TOT3+TOT4+TOT5+TOT6

      DO 75 COUNT = 1,500
         READ(60,*,END=76)EVENT(COUNT)
   75 CONTINUE
   76 CONTINUE
*************************************************************************
*  If there were no rise/set times at all, the following message is *
*  written to the final output file and the program ends.           *
*************************************************************************
      IF (COUNT.EQ.1) THEN
         WRITE(25,*)'There were no opportunities for viewing with this
     + configuration.'
         GOTO 215
      ENDIF
*************************************************************************
*  The following performs a sort to place the list of all events in *
*  order from smallest number to largest.                           *
*************************************************************************
      DO 80 COUNT = 1,TOTAL-1
         DO 78 X = 1,TOTAL-1
            IF (EVENT(X+1).LT.EVENT(X)) THEN
               TEMP      = EVENT(X+1)
               EVENT(X+1) = EVENT(X)
               EVENT(X)   = TEMP
            ENDIF
   78 CONTINUE
   80 CONTINUE

      EVENT(0) = 0.0D0
*************************************************************************
*  The following loops determine the intermediate status of visibil-*
*  ity at each event.                                               *
*************************************************************************
      DO 100 COUNT = 0,TOTAL
            IF (TOT1.EQ.0) THEN
```

```
            TT(COUNT,1) = RS1(IN)
            GOTO 100
         ELSE IF (EVENT(COUNT).EQ.E1(IN+1)) THEN
            TT(COUNT,1) = RS1(IN+1)
            GOTO 100
         ELSE IF (EVENT(COUNT).GT.E1(IN).AND.IN.EQ.(TOT1-1)) THEN
            TT(COUNT,1) = RS1(TOT1)
            GOTO 100
         ENDIF
 90 CONTINUE
100 CONTINUE

    DO 120 COUNT = 0,TOTAL
         IF (TOT2.EQ.0) THEN
            TT(COUNT,2) = RS2(0)
            GOTO 120
         ENDIF
       DO 110 IN = 0,TOT2 - 1
        IF (EVENT(COUNT).GE.E2(IN).AND.EVENT(COUNT).LT.E2(IN+1)) THEN
            TT(COUNT,2) = RS2(IN)
            GOTO 120
         ELSE IF (EVENT(COUNT).EQ.E2(IN+1)) THEN
            TT(COUNT,2) = RS2(IN+1)
            GOTO 120
         ELSE IF (EVENT(COUNT).GT.E2(IN).AND.IN.EQ.(TOT2-1)) THEN
            TT(COUNT,2) = RS2(TOT2)
            GOTO 120
         ENDIF
110 CONTINUE
120 CONTINUE

    DO 140 COUNT = 0,TOTAL
         IF (TOT3.EQ.0) THEN
            TT(COUNT,3) = RS3(0)
            GOTO 140
         ENDIF
       DO 130 IN = 0,TOT3 - 1
        IF (EVENT(COUNT).GE.E3(IN).AND.EVENT(COUNT).LT.E3(IN+1)) THEN
            TT(COUNT,3) = RS3(IN)
            GOTO 140
         ELSE IF (EVENT(COUNT).EQ.E3(IN+1)) THEN
            TT(COUNT,3) = RS3(IN+1)
            GOTO 140
         ELSE IF (EVENT(COUNT).GT.E3(IN).AND.IN.EQ.(TOT3-1)) THEN
            TT(COUNT,3) = RS3(TOT3)
            GOTO 140
         ENDIF
130 CONTINUE
140 CONTINUE

    DO 160 COUNT = 0,TOTAL
         IF (TOT4.EQ.0) THEN
            TT(COUNT,4) = RS4(0)
            GOTO 160
         ENDIF
       DO 150 IN = 0,TOT4 - 1
        IF (EVENT(COUNT).GE.E4(IN).AND.EVENT(COUNT).LT.E4(IN+1)) THEN
            TT(COUNT,4) = RS4(IN)
            GOTO 160
         ELSE IF (EVENT(COUNT).EQ.E4(IN+1)) THEN
            TT(COUNT,4) = RS4(IN+1)
```

```
160 CONTINUE

    DO 180 COUNT = 0,TOTAL
          IF (TOT5.EQ.0) THEN
             TT(COUNT,5) = RS5(0)
             GOTO 180
          ENDIF
       DO 170 IN = 0,TOT5 - 1
        IF (EVENT(COUNT).GE.E5(IN).AND.EVENT(COUNT).LT.E5(IN+1)) THEN
           TT(COUNT,5) = RS5(IN)
           GOTO 180
        ELSE IF (EVENT(COUNT).EQ.E5(IN+1)) THEN
           TT(COUNT,5) = RS5(IN+1)
           GOTO 180
        ELSE IF (EVENT(COUNT).GT.E5(IN).AND.IN.EQ.(TOT5-1)) THEN
           TT(COUNT,5) = RS5(TOT5)
           GOTO 180
        ENDIF
170 CONTINUE
180 CONTINUE

    DO 200 COUNT = 0,TOTAL
          IF (TOT6.EQ.0) THEN
             TT(COUNT,6) = RS6(0)
             GOTO 200
          ENDIF
       DO 190 IN = 0,TOT6 - 1
        IF (EVENT(COUNT).GE.E6(IN).AND.EVENT(COUNT).LT.E6(IN+1)) THEN
           TT(COUNT,6) = RS6(IN)
           GOTO 200
        ELSE IF (EVENT(COUNT).EQ.E6(IN+1)) THEN
           TT(COUNT,6) = RS6(IN+1)
           GOTO 200
        ELSE IF (EVENT(COUNT).GT.E6(IN).AND.IN.EQ.(TOT6-1)) THEN
           TT(COUNT,6) = RS6(TOT6)
           GOTO 200
        ENDIF
190 CONTINUE
200 CONTINUE

    CHANGE = 1
*****************************************************************
*  The following determines if continuous communication is possible.*
*  For 4 satellites, the sum must be greater than or equal to 3.    *
*****************************************************************
     DO 210 COUNT = 0,TOTAL
        SUM = TT(COUNT,1) + TT(COUNT,2) + TT(COUNT,3) + TT(COUNT,4) +
     +        TT(COUNT,5) + TT(COUNT,6)
        IF (SUM.LT.(3.0D0).AND.CHANGE.EQ.1) THEN
           WRITE(25,220)EVENT(COUNT)
           CHANGE = 0
        ENDIF

        IF (SUM.GE.(3.0D0).AND.CHANGE.EQ.0) THEN
           WRITE(25,230)EVENT(COUNT)
           CHANGE = 1
        ENDIF

210 CONTINUE
215 CONTINUE
```

```
      CLOSE(UNIT=STATE+5,STATUS='DELETE')
      CLOSE(UNIT=60)

      CLOSE(UNIT=10,STATUS='DELETE')
      CLOSE(UNIT=11,STATUS='DELETE')
      CLOSE(UNIT=12,STATUS='DELETE')
      CLOSE(UNIT=13,STATUS='DELETE')
      CLOSE(UNIT=14,STATUS='DELETE')
      CLOSE(UNIT=15,STATUS='DELETE')

  220 FORMAT('Communications broken at ',F12.5,' SEC')
  230 FORMAT('Communications re-established at ',F12.5,' SEC')

      RETURN
      END
```

```
************************************************************************
*                      SUBROUTINE GSSCVC4                              *
*    (Ground Station Satellite Continuous Visibility Check (4))        *
*  PURPOSE:  The purpose of this subroutine is to accomplish a         *
*            check for constant visibility between a ground station    *
*            and 3 satellites.                                         *
*                                                                      *
*  VARIABLES:                                                          *
*    INPUT:                                                            *
*      STATE     - File number specifier                               *
*                                                                      *
*    LOCAL VARIABLES:                                                  *
*      CHANGE    - specifies when communcation is broken or re-        *
*                  established                                         *
*      COUNT     - do loop counter                                     *
*      E1,..,E4  - Specifies rise/set time for visibility function     *
*                  a ground station and 4 satellites                   *
*      EVENT     - Array of all rise/set times                         *
*      IN        - do loop counter                                     *
*      RS1,..,RS4 - 1 if the event is a rise; 0 if the event is a set  *
*      SUM       - Sum of RS1,..,RS4 at a given event                  *
*      T         - time zero of any selected visibility function       *
*                  - in this subroutine T is a place holder            *
*      TEMP      - Temporary value used in sort loop                   *
*      TOTAL     - Total number of events                              *
*      TOT1      - Number of events between Ground Station #? and      *
*                  Satellite #1                                        *
*      TOT2      - Number of events between Ground Station #? and      *
*                  Satellite #2                                        *
*      TOT3      - Number of events between Ground Station #? and      *
*                  Satellite #3                                        *
*      TOT4      - Number of events between Ground Station #? and      *
*                  Satellite #4                                        *
*      TT        - Holds all event times and the corresonding          *
*                  status of the visibility function for each          *
*                  viewing path                                        *
*      V         - the first value of the selected visibility          *
*                  function                                            *
*      X         - do loop counter                                     *
************************************************************************
      SUBROUTINE GSSCVC4(STATE)

      REAL*8  E1(0:100),E2(0:100),E3(0:100),E4(0:100),EVENT(0:500)
      REAL*8  RS1(0:100),RS2(0:100),RS3(0:100),RS4(0:100),T,TEMP
      REAL*8  TT(0:500,4),V
      INTEGER CHANGE,CHECK,COUNT,IN,STATE,SUM
      INTEGER TOTAL,TOT1,TOT2,TOT3,TOT4,X

      OPEN(UNIT=41,FILE='STAT1.DAT',STATUS='OLD')
      OPEN(UNIT=42,FILE='STAT2.DAT',STATUS='OLD')
      OPEN(UNIT=43,FILE='STAT3.DAT',STATUS='OLD')
      OPEN(UNIT=44,FILE='STAT4.DAT',STATUS='OLD')
      OPEN(UNIT=60,FILE='TRACKER.DAT',STATUS='OLD')

      REWIND(UNIT=60)

      OPEN(UNIT=10,FILE='VIS1.DAT',STATUS='OLD')
      OPEN(UNIT=11,FILE='VIS2.DAT',STATUS='OLD')
      OPEN(UNIT=12,FILE='VIS3.DAT',STATUS='OLD')
      OPEN(UNIT=13,FILE='VIS4.DAT',STATUS='OLD')
************************************************************************
```

```
      DO 20 COUNT = 1,100
         READ(STATE,*,END=25)E1(COUNT),RS1(COUNT)
         TOT1 = COUNT
   20 CONTINUE
   25 E1(0) = 0.0D0

      IF (TOT1.EQ.0) THEN
         READ(10,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS1(0) = 1.0D0
         ELSE
            RS1(0) = 0.0D0
         ENDIF
      ELSE IF (RS1(1).EQ.(0.0D0)) THEN
         RS1(0) = 1.0D0
      ELSE
         RS1(0) = 0.0D0
      ENDIF
*************************************************************************
*              GROUND STATION AND SATELLITE #2                          *
*************************************************************************
      TOT2 = 0
      DO 30 COUNT = 1,100
         READ(STATE+1,*,END=35)E2(COUNT),RS2(COUNT)
         TOT2 = COUNT
   30 CONTINUE
   35 E2(0) = 0.0D0

      IF (TOT2.EQ.0) THEN
         READ(11,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS2(0) = 1.0D0
         ELSE
            RS2(0) = 0.0D0
         ENDIF
      ELSE IF (RS2(1).EQ.(0.0D0)) THEN
         RS2(0) = 1.0D0
      ELSE
         RS2(0) = 0.0D0
      ENDIF
*************************************************************************
*              GROUND STATION AND SATELLITE #3                          *
*************************************************************************
      TOT3 = 0
      DO 40 COUNT = 1,100
         READ(STATE+2,*,END=45)E3(COUNT),RS3(COUNT)
         TOT3 = COUNT
   40 CONTINUE
   45 E3(0) = 0.0D0

      IF (TOT3.EQ.0) THEN
         READ(12,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS3(0) = 1.0D0
         ELSE
            RS3(0) = 0.0D0
         ENDIF
      ELSE IF (RS3(1).EQ.(0.0D0)) THEN
         RS3(0) = 1.0D0
      ELSE
         RS3(0) = 0.0D0
      ENDIF
*************************************************************************
```

```
      DO 50 COUNT = 1,100
         READ(STATE+3,*,END=53)E4(COUNT),RS4(COUNT)
         TOT4 = COUNT
   50 CONTINUE
   53 E4(0) = 0.0D0

      IF (TOT4.EQ.0) THEN
         READ(13,*)T,V
         IF (V.GT.(0.0D0)) THEN
            RS4(0) = 1.0D0
         ELSE
            RS4(0) = 0.0D0
         ENDIF
      ELSE IF (RS4(1).EQ.(0.0D0)) THEN
         RS4(0) = 1.0D0
      ELSE
         RS4(0) = 0.0D0
      ENDIF
*************************************************************************
*  The following calculates the total number of events between the  *
*  ground station and four satellites.                              *
*************************************************************************
      TOTAL = TOT1+TOT2+TOT3+TOT4
      CHECK = 0
      DO 55 COUNT = 1,500
         READ(60,*,END=58)EVENT(COUNT)
         CHECK = COUNT
   55 CONTINUE
   58 CONTINUE

      IF (CHECK.EQ.0) THEN
         WRITE(25,*)'There were no visibility opportunities with this
     + configuration.'
         GOTO 160
      ENDIF
*************************************************************************
*  The following orders all the events from the smallest to the     *
*  largest.                                                         *
*************************************************************************
      DO 65 COUNT = 1,TOTAL-1
         DO 60 X = 1,TOTAL-1
            IF (EVENT(X+1).LT.EVENT(X)) THEN
               TEMP      = EVENT(X+1)
               EVENT(X+1) = EVENT(X)
               EVENT(X)   = TEMP
            ENDIF
   60 CONTINUE
   65 CONTINUE

      EVENT(0) = 0.0D0

*************************************************************************
*  The following determines the status of communications for each   *
*  possible visibility path at each event.                          *
*************************************************************************
      DO 80 COUNT = 0,TOTAL
            IF (TOT1.EQ.0) THEN
               TT(COUNT,1) = RS1(0)
               GOTO 80
            ENDIF
         DO 70 IN = 0,TOT1 - 1
          IF (EVENT(COUNT).GE.E1(IN).AND.EVENT(COUNT).LT.E1(IN+1)) THEN
             TT(COUNT,1) = RS1(IN)
             GOTO 80
```

```
            GOTO 80
         ELSE IF (EVENT(COUNT).GT.E1(IN+1).AND.IN.EQ.(TOT1-1)) THEN
            TT(COUNT,1) = RS1(IN+1)
            GOTO 80
         ENDIF
 70   CONTINUE
 80   CONTINUE

      DO 100 COUNT = 0,TOTAL
            IF (TOT2.EQ.0) THEN
               TT(COUNT,2) = RS2(0)
               GOTO 100
            ENDIF
        DO 90 IN = 0,TOT2 - 1
         IF (EVENT(COUNT).GE.E2(IN).AND.EVENT(COUNT).LT.E2(IN+1)) THEN
            TT(COUNT,2) = RS2(IN)
            GOTO 100
         ELSE IF (EVENT(COUNT).EQ.E2(IN+1)) THEN
            TT(COUNT,2) = RS2(IN+1)
            GOTO 100
         ELSE IF (EVENT(COUNT).GT.E2(IN+1).AND.IN.EQ.(TOT2-1)) THEN
            TT(COUNT,2) = RS2(IN+1)
            GOTO 100
         ENDIF
 90   CONTINUE
100   CONTINUE

      DO 120 COUNT = 0,TOTAL
            IF (TOT3.EQ.0) THEN
               TT(COUNT,3) = RS3(0)
               GOTO 120
            ENDIF
        DO 110 IN = 0,TOT3 - 1
         IF (EVENT(COUNT).GE.E3(IN).AND.EVENT(COUNT).LT.E3(IN+1)) THEN
            TT(COUNT,3) = RS3(IN)
            GOTO 120
         ELSE IF (EVENT(COUNT).EQ.E3(IN+1)) THEN
            TT(COUNT,3) = RS3(IN+1)
            GOTO 120
         ELSE IF (EVENT(COUNT).GT.E3(IN+1).AND.IN.EQ.(TOT3-1)) THEN
            TT(COUNT,3) = RS3(IN+1)
            GOTO 120
         ENDIF
110   CONTINUE
120   CONTINUE

      DO 140 COUNT = 0,TOTAL
            IF (TOT4.EQ.0) THEN
               TT(COUNT,4) = RS4(0)
               GOTO 140
            ENDIF
        DO 130 IN = 0,TOT4 - 1
         IF (EVENT(COUNT).GE.E4(IN).AND.EVENT(COUNT).LT.E4(IN+1)) THEN
            TT(COUNT,4) = RS4(IN)
            GOTO 140
         ELSE IF (EVENT(COUNT).EQ.E4(IN+1)) THEN
            TT(COUNT,4) = RS4(IN+1)
            GOTO 140
         ELSE IF (EVENT(COUNT).GT.E4(IN+1).AND.IN.EQ.(TOT4-1)) THEN
            TT(COUNT,4) = RS4(IN+1)
            GOTO 140
         ENDIF
130   CONTINUE
140   CONTINUE
```

```
************************************************************************
*  The next DO loop determines if constant communication is         *
*  possible.  If the sum is equal to zero, communication is not     *
*  possible.  If the sum is greater than or equal to one, communi-  *
*  cation is possible.                                              *
************************************************************************
      DO 150 COUNT = 0,TOTAL
         SUM = TT(COUNT,1) + TT(COUNT,2) + TT(COUNT,3) + TT(COUNT,4)
         IF (SUM.EQ.(0.0D0).AND.CHANGE.EQ.1) THEN
            WRITE(25,*)'Communications broken at ',EVENT(COUNT)
            CHANGE = 0
         ENDIF

         IF (SUM.GE.(1.0D0).AND.CHANGE.EQ.0) THEN
            WRITE(25,*)'Communications re-established at ',EVENT(COUNT)
            CHANGE = 1
         ENDIF

  150 CONTINUE
  160 CONTINUE

      CLOSE(UNIT=STATE,STATUS='DELETE')
      CLOSE(UNIT=STATE+1,STATUS='DELETE')
      CLOSE(UNIT=STATE+2,STATUS='DELETE')
      CLOSE(UNIT=STATE+3,STATUS='DELETE')
      CLOSE(UNIT=60)
      CLOSE(UNIT=10,STATUS='DELETE')
      CLOSE(UNIT=11,STATUS='DELETE')
      CLOSE(UNIT=12,STATUS='DELETE')
      CLOSE(UNIT=13,STATUS='DELETE')

      RETURN

      END
```